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The Development of a Horizontal Impact Sled Facility and Subsequent Crashworthiness Experiments

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October 1994

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16. Abstract

The goal of this project was to develop a horizontal impact sled test laboratory for the National Institute for Aviation Research (NIAR) at Wichita State University to effectively serve the aviation industry relative to aircraft seat performance as well as other aircraft components. The fundamental goal was achieved in the fall of 1992, and the ensuing period has been spent testing with at least five commercial clients, three of which were FAA observed certification tests.

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TABLE OF CONTENTS

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LIST OF ILLUSTRATIONS

EXECUTIVE SUMMARY

This report describes the development of a horizontal impact sled for the National Institute for Aviation Research located on the campus of Wichita State University. The development period dates from first inception in 1985 to late 1992 when the laboratory began accepting commercial clients. The two principal sources of funding for this development project were the Federal Aviation Administration (FAA) and the Kansas Technology Enterprise Corporation (KTEC).

The system consists of a test sled equipped with upper and lower probes which slides along two horizontal rails. The sled is propelled by compressed air by means of two horizontal cylinders of different diameters. A single cylinder is used for a test. The sled is capable of attaining initial velocities of approximately 40 feet per second in a distance of approximately 60 feet, followed by a short coasting distance before impact, and finally the controlled impact pulse. The arresting mechanism consists of several mild-steel straps pulling through a roller cage by the sled probes. The sled is capable of providing a peak deceleration pulse of 15 to 35 g's within an 8- to 48- inch displacement and a 60- to 180-millisecond time period.

The design and fabrication contract was awarded on October 17, 1988, and the successful bidder was Via Systems Inc., Goleta, California, under the supervision of Mr. Acen Jordan. Mr. Jordan, as of 1988, had developed several horizontal sleds for automotive industry clients. There were several items that preceded the fabrication contract that bear mentioning. First, it was decided that a massive sled reaction mass had to be provided to prevent any potential runaway sled from damaging a nearby 20-inch water line on the west side of the laboratory building. This decision required the approval of several agencies and interested parties. A second item involved replacement of the sled supporting concrete trench arising from a failure to satisfy the geometric specifications for the horizontal alignment of the sled trench and rails. The sled installation was delayed until August 1990.

The principal equipment that was acquired for the laboratory include a KODAK™ EktaPro™ 1000 high-speed digital television recording system, a 64-channel digital data acquisition system manufactured by DSP Technology, Inc., Fremont, CA. The laboratory has developed several template systems as well as test fixtures that are used in seat certification tests and a wide array of dynamic transducers and instrumentation for data acquisition. The laboratory also acquired four Hybrid II Anthropomorphic Test Dummies (ATD's), two of which are fully instrumented. A high intensity overhead lighting system was developed consisting of six rows of 5000-Watt quartz halogen fixtures in a semicircular umbrella shape over the sled impact area. Each row contains some 12 fixtures resulting in a maximum of 108,000 Watts of illumination. These 72 fixtures are computer controlled in groups of six each, resulting in an incremental value of 9000 Watts for each relay controlled increment.

INTRODUCTION

The National Institute for Aviation Research (NIAR) horizontal impact sled is a deceleration test system capable of providing a peak deceleration pulse of approximately 35 g's over an 8- to 48- inch displacement. The fundamental purpose of the impact sled is to establish a test laboratory capable of performing tests in accordance with the Federal Aviation Administration (FAA) cabin safety air regulations, specifically seat/restraint performance. Basically, seat dynamic performance dynamic standards require a triangular deceleration pulse with peak values between 15 and 35 g's and time durations between 60 and 180 milliseconds.

The dynamic system consists of a sled equipped with upper and lower probes which slides along two horizontal rails. The sled is propelled by compressed air by means of two horizontal cylinders of different diameters. A single cylinder is used for a test. The sled is capable of attaining initial velocities of approximately 40 feet per second in a distance of approximately 60 feet, followed by a short coasting distance before impact, and finally the controlled impact pulse. The arresting mechanism consists of several mild-steel straps pulling through a roller cage by the sled probes.

The horizontal sled is housed in the Impact Dynamics Laboratory, room 109, in the NIAR laboratory building on the campus of Wichita State University. An overview of the laboratory complex is shown in figure 1.

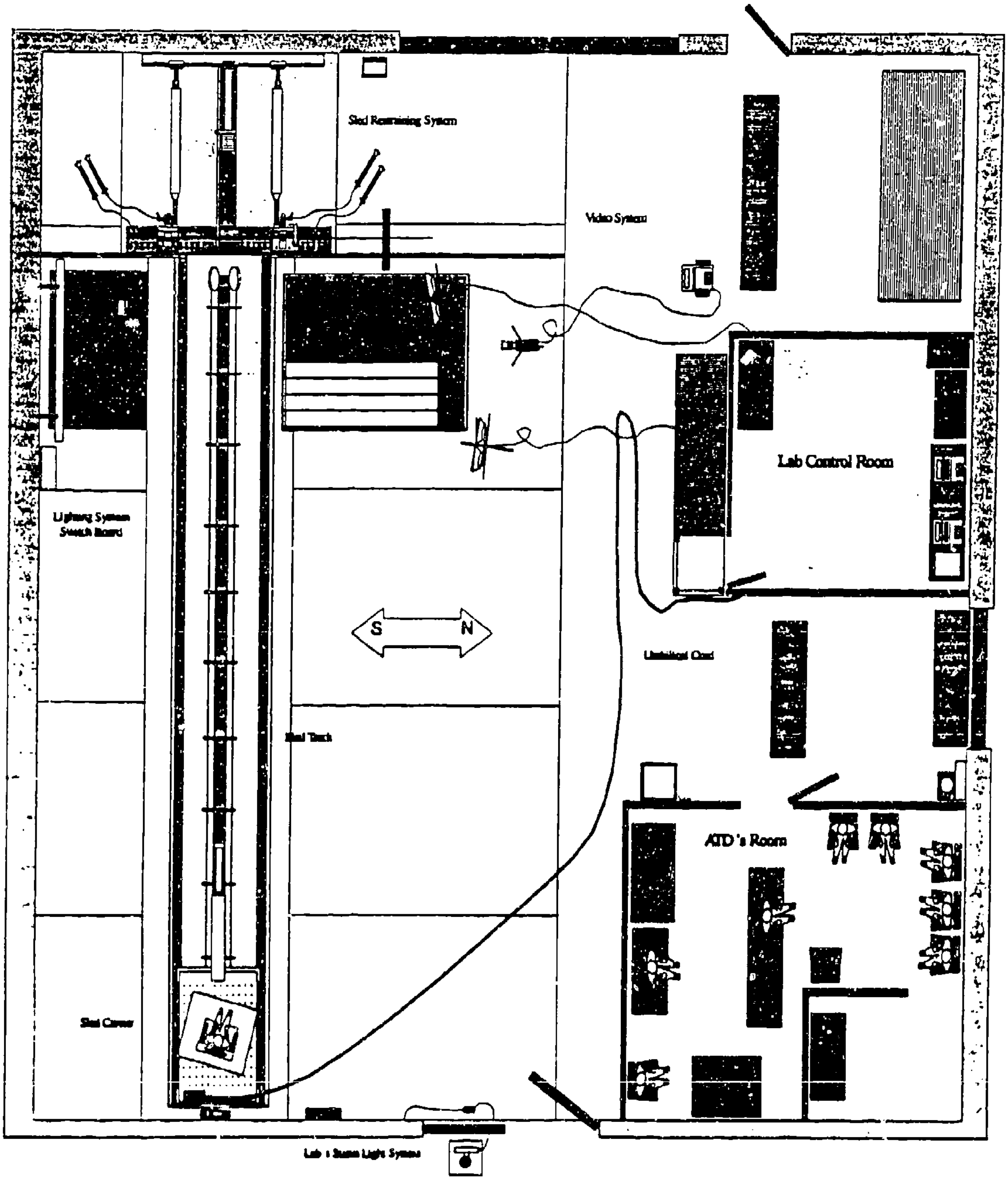


FIGURE 1. LABORATORY OVERVIEW

1985-1990 DEVELOPMENT PERIOD

The genesis for the National Institute for Aviation Research and in particular the horizontal impact sled occurred in 1985. The local commercial aircraft manufactures (Beech, Cessna. LearJet) were faced with new Federal Air Regulations (FAR) relating to seat design and they encouraged Wichita State University to investigate the possibility of developing a laboratory where such seat designs could be tested in accordance with FAA criteria. The basic specifications for the National Institute for Aviation Research crash simulator were drafted in early 1988. There were several revisions to these specifications suggested by interested individuals and potential vendors. The design and fabrication contract was awarded on October 17, 1988, and the successful bidder was Via Systems Inc., Goleta, California, under the supervision of Mr. Acen Jordan. Mr. Jordan, as of 1988, had developed several horizontal sleds for automotive industry clients.

The 1988 Kansas Technology Enterprise Corporation (KTEC) grant served as a major impetus for this activity. The grant was subject to the restriction that the funds could only be used to purchase equipment. Ultimately these funds were used to purchase the KODAK™ High Speed TV System, the Hybrid II dummies, the data acquisition system, seat load cells, and the overhead high intensity lighting system.

There were several items that preceded the fabrication contract that bear mentioning. First, it was decided that a massive sled reaction mass had to be provided to prevent any potential runaway sled from damaging a nearby 20-inch water line on the west side of the laboratory building. This decision required the approval of several agencies and interested parties. A second item involved replacement of the sled supporting concrete trench arising from a failure to satisfy the geometric specifications for the horizontal alignment of the sled trench and rails. The sled installation began in August 1990.

The impact laboratory development was performed under the guidance of Dr. Walter Bernhart, Professor of Aerospace Engineering, whose affiliation started during the summer of 1989. The administrator for the project was Dr. John Hutchinson, Director of Operations, NIAR.

The first major acquisition of the laboratory was a KODAK™ EktaPro™ 1000 high speed digital television recording system in June 1989. September 1989 saw the first FAA proposal for continued development of the impact dynamics laboratory. This proposal involved Dr. Bernhart, Dr. Marc Herniter, Assistant Professor of Electrical Engineering, and Dr. Howard Smith, Professor of Aerospace Engineering at The University of Kansas.
Mr. Richard Chandler served as a most valuable consultant in this development activity. The proposal was awarded in January 1990.

Dr. Herniter was charged with establishing the draft specifications for a data acquisition system. Dr. Herniter and Dr. Bernhart visited several sled facilities in the Detroit area in

January 1990 in support of this task. In April 1990, a request for quotation was issued with a system manufactured by DSP Technology, Inc., Fremont, California, serving as a desired standard. The initial specifications for a overhead lighting system were drafted during the spring of 1990.

In April 1990, a position description for a sled manager was issued and several applicants were interviewed for this position. The Impact Dynamics Laboratory was indeed fortunate to acquire Mr. Joseph Mitchell for this position in July 1990.

The horizontal impact sled was installed during late August by Mr. Jordan and other VIA personnel and four acceptance tests were conducted on August 31, 1990. This period also saw the first graduate student affiliated with the laboratory. This student was Mrs. Marilyn Henderson, who was charged with the responsibility of transferring and plotting data acquired on a 2-channel digital oscilloscope. This mode of operation, although slow and laborious, was the only means of displaying test data until the DSP data acquisition system was operable in June 1991.

The fall of 1990 was spent in establishing the design and specifications for a template system for the sled as well as the required basic dynamic transducers and instrumentation for data acquisition. Mr. Mitchell began the task of acquiring Hybrid II Anthropomorphic Test Dummies (ATD's) as well as the first draft of the sled protocol and safety measures. It is noteworthy to mention that this protocol documentation has gone through several revisions, the lastest version entitled "Horizontal Test Sled: Technical Order, June 1993," is included as appendix A of this report and was authored by Mr. Mitchell.

The impact dynamics laboratory was also most fortunate to acquire Mr. Juan Rodriguez, a second graduate student in October 1990. Mr. Rodriguez has been continuously affiliated with the laboratory and has performed numerous tasks associated with the sled development. His first assignment was to develop the fabrication drawings for the sled template structure and ballast plates, which were completed and submitted for competitive bids in November 1990. In December Mr. Rodriguez and Mr. Manoj Rahematpura visited the Civil AeroMedical Institute (CAMI), Oklahoma City, OK, to establish the basic geometry and features of the test fixtures to comply with FAR Parts 23 and 25.

1991 DEVELOPMENT PERIOD

The template structure was installed in January 1991, and the DSP data acquisition system was delivered on April 8, 1991. This period was spent in preparing sketches of seat test fixtures, preparing the umbilical cord for the sled, and shop drawing preparation of the overhead light support system.

The first meeting of the Impact Sled Advisory Committee was held on March 23, 1991. Representatives from University of Kansas, Beech Aircraft, Cessna Aircraft, LearJet,

Boeing, and the FAA were present. The discussion centered on the status and goals of the laboratory. Discussions related to the FAA required triangular pulse shapes were explained with the concept shown in Figure 2. Deceleration Pulse Analysis. When the velocity and deceleration are plotted vs. displacement, it is seen that the velocity is reduced to one half of its initial value when the sled has traveled 5/6 of the total permitted displacement, thus the concept of strap pull through must be employed to reduce the velocity to zero in the remaining 1/6 displacement. The ordinate labeled Normalized Force is approximately proportional to the deceleration.

Mr. Richard Chandler visited on June 6, 7 to discuss a suggested test program that would enhance the pulse shaping capability of the laboratory. The suggestion was to conduct an extensive static test program that would include steel straps being completely pulled through the roller cage. DSP Technology representatives visited the laboratory on June 13,14 to instruct the staff in the appropriate use of the data acquisition system. KODAK™ representatives visited the laboratory on June 10, 12 for training sessions. During these sessions, resolution evaluations of representative 1000 frame/second total absolute motion views were conducted. Thus, while the resolution provided by the 240 horizontal and 192 vertical pixel count is excellent for viewing the event, it fails to capture the fine detail associated with a seat element approaching collapse or other structural failure phenomena. The KODAK™ EktaPro™ 1000 system is an excellent device for an immediate slow motion review of the test. It also has the added capability of down loading the captured event to a standard VHS video format. KODAK™ also announced that a sled mounted imaging head was being developed which would provide considerable improvement in resolution of the relative motions occurring on the sled.

The static test program was performed in August and September 1991 with approximately 100 tests which involved the two strap thicknesses, three strap widths, and four different stance values between the clamp and roller cages. In addition, approximately 30 tests were conducted with the straps being pulled through the roller cage in an attempt to match the force vs. displacement characteristics associated with a triangular temporal pulse. The static test program was conducted by Mr. Juan Rodriguez and Mr. Karl Petzold, who joined the project in August 1991. The static test data was presented in the September progress report. The remainder of the fall 1991 semester was spent in synthesizing these test data and a geometric model of a strap pulling though the roller cage into a pulse prediction capability. The data base for this effort has improved with each succeeding test and has culminated in the document entitled, "An Overview of Procedures in the Impact Dynamics Laboratory, June 1993." The document is included as appendix B of this report and was authored by Mr. Petzold and Mr. Rodriguez.

During this test period, a bartered exchange with Cessna Aircraft Co. was developed wherein they could place selected products on these sled trial tests in exchange for their fabrication of the warped seat track test fixtures. Load cells for the test fixtures were purchased by the NIAR.

Mr. Richard Chandler visited the laboratory on December 16,17, 1991, to resolve several problems associated with establishing a velocity profile by integrating the acceleration traces in accordance with the provisions of two applicable aerospace standards:

SAE AS8049 AEROSPACE STANDARD (1990-07)
Performance Standard for Seats in Civil Rotorcraft
and Transport Airplanes
APPENDIX A: Procedure for Evaluating Impact Pulse Shapes

SAE J211 OCT88 Instrumentation for Impact Test

1992 DEVELOPMENT PERIOD

Early in January 1992, a numerical integration code was written to integrate the deceleration pulse from the initial launch time to the pulse completion. This code was written by Dr. John Hutchinson and Mr. Mitchell. This code replaced some ill fated effort to develop a velocity measuring system by attaching some 80 to 100 magnets to the sled carriage which served to trigger a stationary Hall Effect device providing a discrete set of pulses measured in microseconds. The system performance proved to be very erratic which was attributed to the occasionally skipping of one or more of the magnets during the pulse deceleration period.

The NIAR initiated a series of weekly meetings staring with the new year. These meetings included most researchers who would ultimately use the sled as well as the sled development personnel. One positive outgrowth of this activity was the incorporation of a simple adiabatic expansion mathematical model of the pneumatic system which was suggested by Dr. Steve Hooper, Associate Professor of Aerospace Engineering. The frictional parameters in the model have been tuned to the sled behavior to the extent that it is used to calculate the acceleration time to propel the sled to the desired initial velocity of the pulse. and then permitting a short time interval of non-accelerated motion immediately prior to the impact. The model is described in appendix B, Section 4.5.

Dr. Steven Skinner, Assistant Professor of Electrical Engineering joined the impact dynamics laboratory effort for the spring semester and summer 1992. Dr. Skinner was assigned the tasks of establishing a computer controlled common time base for the entire system. The goal was to utilize a separate personal computer as a clock to supply trigger signals to the various passive devices as needed. These include the DSP data acquisition system, the KODAK™ high speed TV system, the overhead high intensity lighting system, the pneumatic system, and the velocity trap.

Mr. Chandler attended one of the weekly meetings in February. The KODAK™ high speed TV system was one item of discussion where Mr. Chandler suggested that the position of one imaging head should be permanently located and perhaps protected by a

steel cage. He also indicated that a white backdrop inscribed with a grid pattern produces parallax problems and he recommended a simple drop cloth with the NIAR logo and a number, time and date identifier for the test. A tentative pricing schedule was also discussed. The Cessna Aircraft Company conducted some side facing seat tests during February and March 1992.

The structural support system for the high intensity overhead lighting system was erected during March. A 180 millisecond test was attempted that required a sled travel of approximately 48 inches. This excessive stroke permitted the upper probe to depart from its constraint system and caused some damage to the probe. The internal adjustment system for the probes was a continuously threaded 1.25 inch diameter rod which had buckled. A decision to replace this threaded rod adjustment with a more positive procedure of simply bolting the inner and outer probes together at 2- inch intervals. This modification does require more time to change the probe length; however, experience has shown that the probe lengths are changed infrequently

During April 1992, a status report was prepared for the FAA quarterly briefing scheduled for April 22, 23. During this briefing, it was announced that the DSP data acquisition system would be upgraded from 48 to 64 channels, 60 of which would be strain gage amplifiers, and a preliminary fee schedule for the laboratory had been developed. Representative pulse shapes were also presented.

The month of May found the laboratory engaged in a series of tests with clients that gave the NIAR facility the opportunity to utilize the yaw and roll fixture, the seat load cells, the instrumented Hybrid II dummies, evaluation of the head injury criteria (HIC) and other data. Fortunately, these tests also revealed that the DSP data channels associated with the rigid body sled motions were improperly filtered. The SAE J211 calls for a Channel Class 60 filter for these data with a 9 to 24dB per octave rolloff above the cutoff or corner frequency, FN. The DSP eight-pole Butterworth filters have a rolloff of approximately 48dB per octave above the cutoff or corner frequency which is somewhat in excess of the J211 requirement. This created a time shift of the peak accelerations between the Class 60 and Class 180 filtered traces.

This problem was presented to Mr. Tim Lewinski of DSP Technology. Fortunately, DSP maintains active membership on the SAE Safety Test Instrumentation Standards Committee which had appointed a New Filter Corridor Task Force Subcommittee to address this specific problem. The subcommittee met four times between November 1991 and June 1992. Mr. Lewinski forwarded the most probable recommendation of the subcommittee which was implemented by the NIAR in early July. This filter concept was reviewed with Mr. Richard Chandler in late July and he recommended that the laboratory provide this description to both clients and test approval agencies. The published statement was as follows:

The NIAR utilizes a data acquisition system manufactured by DSP Technology Inc., Fremont, CA. This system utilizes analog presample filtering followed by a 12 bit analog to digital conversion. The FN, or corner frequency of the 8-pole Butterworth presample analog filter is set to 2900 Hertz for a sample frequency of 10,000 Hertz. This is well below the Nyquist frequency and exceed the recommendations of SAE J211, Sections 9.1 and 9.2. These data are then processed by a 2-pole Butterworth digital filter utilizing both a forward and backward pass to eliminate the phase shifts that are characteristic of all recursive (nonsymmetric) filters. This operation will serve to eliminate the time shifts in the filtered data. The double pass operation is also equivalent to a 4-pole filter and is consistent with SAE J211, Section 9.4.1. A CFC-60 filter requires a FN value of 100 Hertz, while the required value for a CFC-180 filter is 300 Hertz. The recommendations of the SAE New Filter Corridor Task Force is to increase the FN frequencies by 25 per-cent, resulting in 125 Hertz for CGC-60, 375 Hertz for CFC-180, and 2062.5 Hertz for CFC-1000. These recommended FN values are used in the NIAR digital filter codes.

When the aforementioned DSP upgrade was installed in early October, the modified DSP software, IMPAX, included these recommendations, and is fully described in Section 5.9.1 of appendix B.

In July 1992, the laboratory was experiencing some cable fraying problems in the pneumatic propulsion system. The laboratory was inoperative for several weeks awaiting replacement nonfraying cable replacements. This down time was also utilized to modify the lower probe by replacing the threaded rod adjustment mechanism with the identical bolted mechanism used on the upper probe in March 1992.

The high intensity overhead lighting was completed in late September 1992. The system contains six rows of 5000 Watt quartz halogen fixtures in a semicircular umbrella shape over the sled impact area. Each row contains some 12 fixtures resulting in a maximum of 108,000 Watts of illumination. These 72 fixtures are computer controlled in groups of six each resulting in an incremental value of 9000 Watts for each relay controlled increment.

Dr. Skinner modified the existing control panel to include all of the time triggered functions with master control by a second PC identified as Computer B which executes the software code CRASHV and is fully described in section 5.7 of appendix B.

The Small Aircraft Manufacturers Association (SAMA) utilized the laboratory in December. The tests were coordinated by Dr. Steve Hooper.

1993 DEVELOPMENT PERIOD

During January 1993, several dynamics laboratory personnel attended a FAA short course on aircraft seat testing. The activity was conducted at CAMI by Mr. Van Gowdy and Mr. Steve Soltis.

The laboratory tested several seats manufactured by ERDA on Feb. 3,4. These tests were coordinated by Mr. Steve Soltis. Several seat cushion tests for SAMA were also conducted.

A new and revised sled template was ordered in April. This new template structure will be machined from a single 2-inch-thick 2024 aluminum plate. The template will be approximately 4 inches wider and will weigh approximately the same as the existing template system. The most significant change is replacing the existing 17 pieces with but three structural elements. In addition, a yaw template was also ordered that will accommodate three abreast seating.

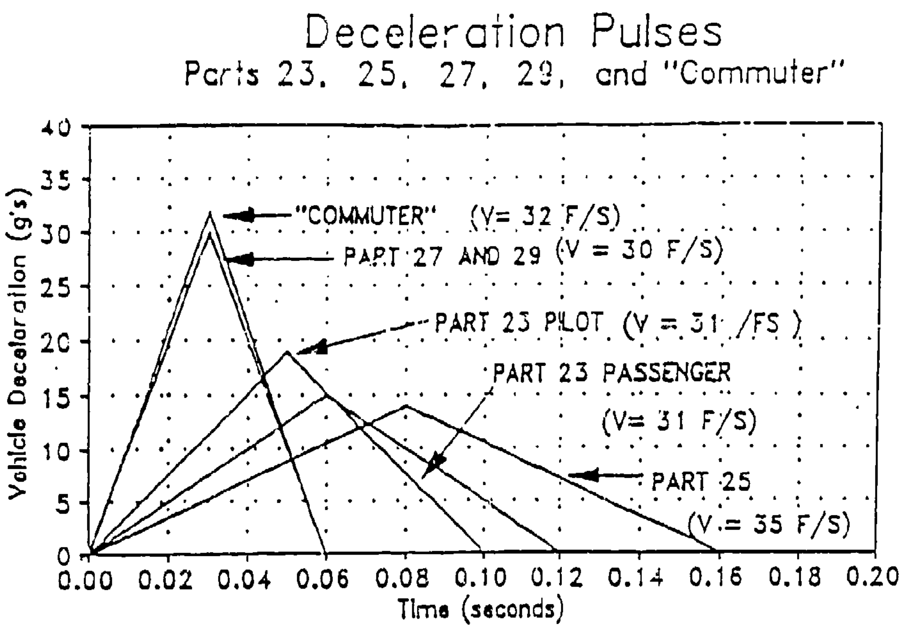
An Advisory Committee meeting was held on May 5, 1993. Mr. Chandler and several industry representatives were in attendance. The laboratory status was reviewed by Mr. Mitchell and Dr. Bernhart

Mr. Mitchell stressed the point that the past laboratory staff consisted of himself as the only full-time employee, two graduate research assistants, and one undergraduate assistant has now been expanded to three full-time employees and six graduate and undergraduate research assistants. The VITA of the present staff members are given below. He also pointed out that the safety and protocol issues have been documented in the form of appendix A, and the laboratory operation manual has been developed as appendix B. Mr. Mitchell also identified a laboratory deficiency in the form of a limited high-speed photometric data acquisition capability. The laboratory staff are currently examining the latest high-speed TV capabilities as well as high speed film systems.

Dr. Bernhart also emphasized that the laboratory has a need to begin the development of a transducer and dummy calibration capability conforming to the published requirement for ATD's. The Committee suggested that the laboratory could offer dummy calibration as part of its customer service.

CONCLUSIONS

The objective of this program was to develop a horizontal impact test sled capable of performing certification tests of aircraft seats and other components. The laboratory has had six clients since August 1992 for various test programs. The NIAR billed cost of these programs is approximately $155,000 to date. Three of these have been FAA observed certification tests. The laboratory is currently (June 1993) conducting tests of wheelchair restraining systems in transportation vehicles. This test activity requires a rectangular deceleration pulse and the laboratory personnel have developed the appropriate strap configuration for this condition. These demonstrated capabilities suggest that primary objective has been satisfied.



Pulse Duration Tau seconds	Initial Velocity Vo F/S	Peak Acceleration 2Vo/Tau G's	Maximum Stroke Displacement VoTau/2 inches
0.060	32	33.13	11.52
0.060	30	31.06	10.80
0.100	31	19.26	18.60
0.120	31	16.05	22.32
0.160	35	13.59	33.60

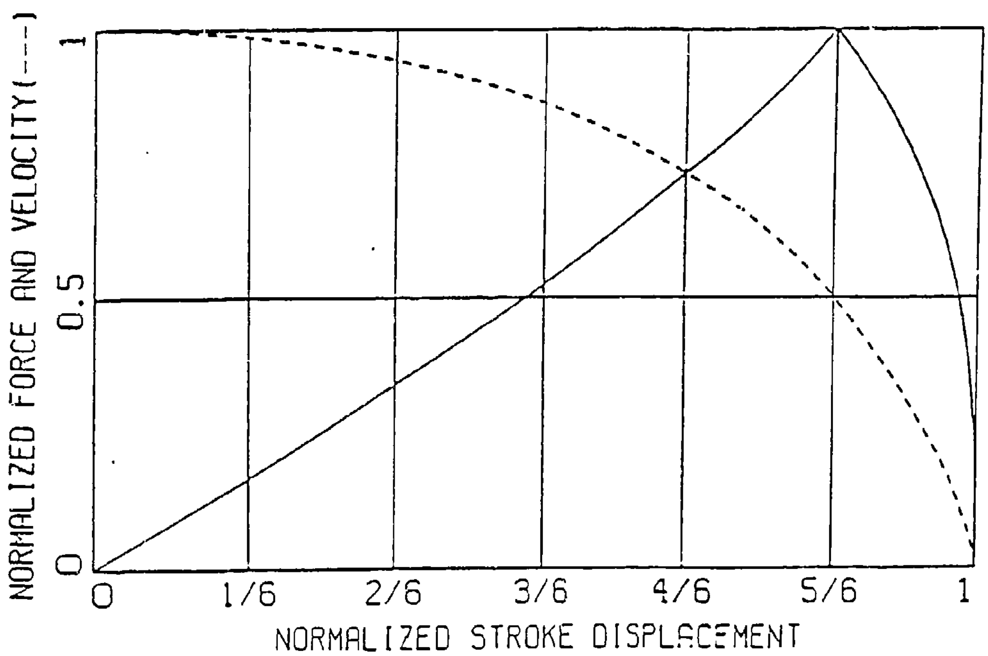


FIGURE 2. DECELERATION PULSE ANALYSIS

APPENDIX A

Horizontal Impact Test Sled
Technical Order
June 1993

Joseph A. Mitchell
NIAR/Impact Dynamics Laboratory

Table of Contents

Rev: 6/04/93

Table of Figures

Rev: 6/03/93

1.0 INTRODUCTION

1.0.1 PURPOSE:

This Technical Order establishes practices for the uniform operation of the Impact Dynamics Laboratory. It provides guidelines within which the laboratory will be operated. This publication also provides step-by-step instructions for the accomplishment of all phases of the HITS operation.

1.0.2 SCOPE:

This Technical Order is applicable to the Impact Dynamics Laboratory operated by the National Institute for Aviation Research.

The procedures and criteria contained in this Technical Order are based upon the VIA Systems HITS Operational Manual, revised 10/90.

1.0.3 SAFETY:

The keynote for the design of the Impact Dynamics Laboratory was personnel safety. The incorporation of numerous safety devices and concepts was based largely on this consideration.

1.0.3.1 Responsibility -

For a safety program to work, every person must assume the responsibility. Although the Lab Manager is the responsible agency for safety, all personnel must take responsibility for practicing and enforcing the safety program.

1.0.4 IMPACT DYNAMICS LABORATORY SUB-SYSTEMS

A. Horizontal Impact Test Sled (HITS)
B. Data Acquisition System
C. Anthropomorphic Test Dummies (ATDs)
D. High Speed Camera System

1.1 NOTICE OF PROTOCOL

Impact Dynamics Laboratory
National Institute for Aviation Research
The Wichita State University

The keynote for the design of the Impact Dynamics Laboratory was personnel safety. The incorporation of numerous safety devices and concepts was based largely on this consideration. The intent of the visual safety warnings (OSHA 1910.23 AND 1910.144) is to promote immediate attention to the hazard areas within the laboratory.

For a safety program to work, every person must be *safety responsible*. Although the Lab Manager is the responsible agency for safety, all personnel must take responsibility for practicing and enforcing the safety program.

This Notice of Protocol establishes practices for the uniform operation of the Impact Dynamics Laboratory. It provides guidelines within which the laboratory will be operated.

The Laboratory Manager will exercise sole command over all functions, procedures and operations during the test program launch phase.

All personnel, active on the test or observing it, will be restricted to designated safe areas in the last moments before launch. No deviation authorized without the explicit consent of the Laboratory Manager.

In the event of a HITS system failure, no one will leave their designated safe area until the laboratory has been declared safe. This declaration will be made by the Laboratory Manager. At that time, all non-essential personnel will be escorted from the laboratory.

A LAB STATUS light assembly will be situated near the main entrance to the laboratory whenever a test program is in progress or periodic maintenance is being performed. The lab status light assembly is a three-bulb light panel: green, yellow and red. Each light, when singly lit, will indicate the current status of the propulsion system and level of lab safety to be observed.

The GREEN light indicates a non-activated propulsion system. Under the GREEN light, lab operations, to include periodic maintenance (visual and 7-day), payload preparation/loading and payload inspection, may proceed with an emphasis on safety.

The YELLOW light indicates an activated, SAFE propulsion system. Under the YELLOW light, lab operations, to include periodic maintenance (30-day), mating of payload to launch station and lab subsystems preparation, may proceed with a heightened safety awareness.

The RED light indicates an extreme hazard condition exists within the lab: initiation of test program launch sequence. Under the RED light, all lab personnel, clients and observers are to assemble within their designated safe area. No one will be allowed admittance to the lab without the direct authorization of the Laboratory Manager.

1.1.1 GENERAL CAUTIONS:

The following cautions are presented here to provide additional guidelines for the proper operation of this laboratory:

CAUTION DO NOT INSTALL WASHERS ON DECELERATOR COLUMNS. They will shatter under load.

CAUTION DO NOT BOLT DOWN AIR TANKS. Should motor break loose, there will be no rigidity in manifolds; tanks will move; less probability of manifold shearing and a vast amount of compressed air escaping into the laboratory.

CAUTION The proper placement of motor cables along cable guideway: small motor cables to the inside of large motor cables.

CAUTION UNLESS OTHERWISE STATED, torque all grade 5 bolts to 60 ft. lbs; all grade 8 bolts to 90 ft. lbs.

CAUTION Replace all worn or damage bolts with the proper grade bolts (i.e. grade 8 with grade 8).

CAUTION Track crossing is accomplished by way of removable walkways.

CAUTION All loading operations of payloads exceeding 70 lbs must be accomplished by two people or with the material handling gantry.

Rev: 06/03/93

2.0 TEST PROGRAM

WARNING

THE SLED PROBES ARE
NO STEP
AREAS.

2.1

Activate the Lab Status Light Assembly to GREEN.

2.1.1 Test Article Preparation

Insure carriage is positioned within designated loading zone.

2.1.2

Position gantry and payload directly above carriage payload platform. Lower payload onto platform. Insure probes and probe attach points are not struck or otherwise disturbed.

2.1.3

Secure payload to platform using proper hardware.

2.1.4

Position sled and payload to the rear of the decelerator station with the aid of a come-along device. DO NOT ALLOW LOWER PROBE TO EXTEND OVER THE CABLE REEL ASSEMBLY. Figures 1, 2, 3, 4 and 5 are to be used as references for the following preliminary probe alignment checks.

2.1.4.1

Refer to Figure 2: Very carefully and with the aid of the come-along device, pull the sled probes into the decelerator station. Observe the lower probe as it passes over the cable reel assembly. Insure adequate clearance. It may be necessary to position a person in the decelerator pit in such a manner that their vantage point is directly facing the lower probe. Inadequate clearance requires immediate correction. See: Probe Alignment, Lower.

2.1.4.2

Refer to Figures 3, 4 and 5: If necessary, retract carriage from decelerator station. Now observe the upper probe as it enters into the decelerator station. Correct alignment of the vertical position is indicated by the flat sole of the upper probe shoe engaging the flat surface of the decelerator station. Probe shoe bevel contacting decelerator station bevel is an indication of a low vertical probe alignment and requires immediate correction. See: Probe Alignment, Upper.

2.1.4.3

Refer to Figures 4 and 5: Reposition sled to rear of decelerator station. Insure sled is positioned laterally against south rail. Again observe the upper probe as it enters into the decelerator guideway. Any indication that the upper probe is trying to yaw, left or right, requires immediate correction. See: Probe Alignment, Yaw.

NOTE

Realignment of either probe requires repeat performance of Section 2.1.5.

2.2 DECELERATOR PREPARATION

NOTE: For models with dual decelerator systems.

2.2.1 Changing the stance: moving the decelerator cages

WARNING

A 300 lb. capacity bracing device (sawhorse) must be in place underneath the lower decelerator columns during all maintenance and adjustments. Placement of bracing device should be at *CG* of column. (*CG* indicated by blue dot)

<u>Refer to Figure 6</u>: The lower decelerator cages are held in place by two screws threaded into the decelerator plate and by a slot and key on the rear edge of the base plate.

This allows the cages to slide along the decelerator plate without having to be otherwise supported. When sliding the cages and their reaction columns, care should be exercised to keep them square to the decelerator plate, as otherwise the key could disengage from the slot and allow the cage assembly to fall.

2.2.1.1

Remove the transverse allthread rod assembly.

2.2.1.2

Pump up the hydraulic rams so that the slides on the cages are fully in.

2.2.1.3

Loosen and remove the screws holding the cage to the decelerator plate.

2.2.1.4

Loosen the four (4) screws holding the forward end of the reaction columns to the reaction beam.

CAUTION

Do not remove
these screws!

2.2.1.5

Loosen the heavy counter nut on the threaded portion of the reaction column.

2.2.1.6

Slide the cage/reaction column assembly into the new position.

2.2.1.7

Secure the cage to the decelerator plate with two screws.

2.2.1.8

Adjust the length of the reaction column at the threaded portion so that it engages the reaction beam properly. It may be necessary to lubricate the column clamp assembly at the reaction beam interface to allow easier adjustment (use vaseline or similar lubricant).

2.2.1.9

Fully tighten the screws clamping the reaction column to the reaction beam. Make sure that column and reaction beam are square to each other.

2.2.1.10

Fully tighten screws securing the cage to the decelerator plate. DO NOT OVER TORQUE.

2.2.1.11

Repeat operation on opposite cage. Make sure the stance is symmetrical. Replace the transverse allthread rod and tighten the nuts as follows:

2.2.1.12 Allthread Rod Installation

Run up the inside nuts to the cage and tighten one of them 1/8 turn to pre-load the allthread rod. Run up the outside nuts and tighten with wrenches. Make sure allthread does not turn while tightening the nuts.

2.2.2 LOADING THE DECELERATOR

2.2.2.1.

Check that the transverse allthread rod is in place and the nuts are tight. Check that cages are tightly secured to decelerator plate. Check that breech screws are tight.

2.2.2.2

Release hydraulic pressure and allow cage slides to go out as far as possible.

2.2.2.3

Slide band in from the roller cage side, allowing minimum of six inches of band to stick out past the clamp cage.

2.2.2.4

Adjust the position of the band so that it is symmetrically distributed about the width of the rollers of the roller cage and the columns of the clamp cage. Use wood or metal gauges or supports as necessary to accomplish this.

DANGER

After performing Steps 2.2.2.5 and 2.2.2.6,
DO NOT REMOVE HYDRAULIC PRESSURE
from jacks until ready to unload decelerator.
Lack of hydraulic pressure will result in total
failure of decelerator station.

2.2.2.5

Pump up the hydraulics on the roller cage until the timing marks on the lower slide are aligned.

2.2.2.6

Pump up the hydraulics on the clamp cage until the timing marks are aligned.

2.3 VSDI: Optical Sensor Positioning

2.3.1

Refer to Figure 7. Loosen Optical Sensor Unit slide rail retaining bolt, but do not remove.

2.3.2

Slide sensor along rail to insure ease of adjustment. Lubricate rail with WD-40 (or equivalent) if necessary.

2.3.3
Position sled at rear of decelerator station so that the upper probe engages the decelerator steel straps.

2.3.4

Slide sensor into position. The velocity reading must occur within the final 1 inch of sled travel prior to engaging the decelerator straps. This places the sensor to the rear of the target blade.

2.3.5

The target blade should be centered within the center of the sensor gate. This will allow for vibration or shock motion that may be transmitted to the target and reduce the possibility of the target striking the sensor body.

2.3.6

Check that the target blade is fastened securely; straight, not bent, twisted or otherwise damaged.

2.3.7

Hand tighten the sensor slide rail retaining bolt.

2.3.8 VSDI Operational Check

Turn unit ON. Press RESET. Display should read "--.-0" ms., and the READY light should be ON.

2.3.8.1

Pass a pencil, or other narrow object quickly through the optical beam. The display of the VS200 should now read some value of time in milliseconds. The READY light should be

OFF. *For the VS200, any furthur attempt to cut the optical beam should not disturb the time reading.*

2.3.8.2

Push RESET to rezero the unit and set the logic. The unit is now ready for operation.

2.3.8.3

In operation, the readout is the time that the target blade takes to pass through the optical beam. Since the beam is very small (0.010"), the transition time required to switch the beam is very short. In addition, electronic pulse shaping is used to shorten the switching risetime. It is important that the optical slots be kept clean to preserve the sharp switching characteristics. Velocity is obtained by use of the formula:

$$V = d/t$$

or velocity, V, equals distance traveled divided by time where the units of V and d are the same. If a 1 inch target blade is used, velocity in inches per second is obtained by dividing the time in seconds into 1 inch. Any unit system of velocity can be obtained by simply expressing the width of the target blade in the appropriate units.

2.4 PRE-LAUNCH CHECKLIST

WARNING

Insure non-used propulsion system is entirely disarmed. *Entirely disarmed* is defined as no charge on the tanks and not disconnected to launch control panel.

NOTE

The carriage should be positioned at the loading zone.

2.4.1 Pre-launch Inspection

Decelerator is correctly loaded; hydraulic valves are closed; and hydraulic jack handles are in the raised position.

2.4.2

Both transverse allthread rods are in place and secured.

2.4.3

Emergency decelerators are in place.

2.4.4

Decelerator reaction columns are aligned and secured.

2.4.5

Propulsion systems main pressure control valves (south pit - 2 ea.) are closed (handles in **up** position).

2.4.6

Air pressure in propulsion control system is at 60 psig. If not correct, adjust regulator at compressor output.

2.4.7

Propulsion control valves (south and north pits) are closed.

2.4.8

Arming control valves (south and north pits) are closed.

2.4.9

Carriage probe rollers (upper and lower) are free to turn. Both probe feet are in place and secure.

2.4.10

Tow cables are clear and in the grooves of the sheaves.

2.4.11

VSDI sensor is correctly positioned. If incorrect, see *Section 2.3, VSDI: Optical Sensor Positioning* for instructions.

2.4.12

Load decelerator(s) with steel bands. INFO: The steel band requirements are dictated by the test requirements of the applicable FAR.

2.4.13

Position sled and payload at launch station using the capstan and motor.

2.4.14 Winch Operating Procedures

Attach tow cable to tow-point located aft section of sled.

2.4.14.1

Wind cable around capstan in such a manner that the cable enters the capstan from below; winds around capstan four times; and, exits from above.

2.4.14.2

With cable wrapped loosely around capstan, turn on motor.

2.4.14.3

Firmly grasp cable with both hands. Pulling the cable taut will cause cable to tighten around capstan, which in turn will pull sled slowly toward the launch station. Relaxing the pull on the cable will cause the sled to stop.

Halt the sled twelve inches in front of the launch station.

2.4.15 PROPULSION CONTROL SYSTEM CHECK

AT THIS TIME, PERFORM THE APPROPRIATE PROPULSION SYSTEM CONTROL CHECK, SECTION 2.4.15.1 OR SECTION 2.4.15.7.

2.4.15.1 Auxiliary Propulsion System

Connect Auxiliary controls (grey) to launch panel.

2.4.15.2

Open auxiliary main pressure control valve.

2.4.15.3

Pressurize air storage tank to 20 psi.

2.4.15.4

On launch control panel, set DELAY for 5 seconds.

2.4.15.5

Initiate launch sequence; activate FIRE switch at Lab Manager's command.

2.4.15.6

After completion of check, lock FIRE switch.

2.4.15.7 Main Propulsion System

Connect Main controls (yellow) to launch panel.

2.4.15.8

Open main main pressure control valve.

2.4.15.9

Pressurize air storage tanks to 20 psi.

2.4.15.10

On Launch control panel, set DELAY for 5 seconds.

2.4.15.11

Initiate Launch sequence; activate FIRE switch at Lab Manager's command.

2.4.15.12

After completion of check, lock FIRE switch.

2.4.16

Deactivate the launch station safety switch - Safety OFF.

2.4.17

Attach yoke (small for propulsion south, large for propulsion north) to sled yoke attach point. Secure with red, threaded grade 8 bolt.

DANGER

Failure to comply with the next step
could result in system damage
or personnel injury.

2.4.18

Secure remaining yoke to lower attach point of launch station with grade 8 bolt and nut.

2.4.19

With the aid of winch, pull sled into launch station. Activate safety switch (safety ON). Turn on SAFETY light assembly. A green light should be visible.

2.4.20

Disconnect and stow winch cable.

2.4.21 Launch Station Probe Alignment Check

Refer to Figure 8. Slide Probe Alignment Fixture into place. Upper probe should clear upper surface of fixture while lower probe should clear lower surface of fixture. If any doubt exists about probe alignment, return sled to decelerator station and reaccomplish Section 2.1.4.

AT THIS TIME, THE PAYLOAD SHOULD BE APPROVED FOR TEST; PAYLOAD AND SLED IN CORRECT LAUNCH POSITION; SAFETY PIN IS ENGAGED; AND, SAFETY INDICATOR IS GREEN.

2.5 LAUNCH CHECK LIST

NOTE

At this time, all lab personnel, clients and observers are to assemble within their designated safe areas.

2.5.1

Lab status light to RED.

2.5.2

Open propulsion system main pressure control valve (handle down). Non-used propulsion system main pressure control valve remains closed (handle up). Pressurize tanks; stabilize at requisite firing pressure; monitor pressure setting by observing transducer digital meter.

If tank pressure does not stay within preset limits, activate vent switch. Insure system SAFETY is on. De-pressurize tanks for a zero pressure reading. Troubleshoot and correct system pressure malfunction. Repeat Pre-Launch Inspection, Section 2.4.1.

2.5.3

Start Launch sequence to include:

2.5.3.1

Arming System.

2.5.3.2

Safety OFF - indicator is RED, aural warning tone activated.

2.5.3.3

Activate data acquisition system and cameras.

2.5.3.4

Unlock FIRE switch.

2.5.3.5

Activate FIRE switch. Once sled is under way, engage SAFETY: Green indicator on, aural warning tone off.

2.6 POST-LAUNCH CHECKLIST

2.6.1

Arming and propulsion control valves are closed (automatic).

2.6.2

Remote safety is ON. Observe visual indicator at launch station -GREEN light ON, aural warning OFF.

2.6.3

Launch control panel FIRE switch is locked out.

2.6.4

Propulsion cylinder is de-pressurized (automatic). Monitor pressure system digital meter for zero tank pressure. Activate VENT switch on control panel, if necessary.

2.6.5

Emergency decelerators are intact, in place and NOT in contact with carriage probe.

2.6.6

Unlock lab entrances, LAB STATUS light to YELLOW.

2.6.7

Perform the following inspections IAW *Section 4, Inspection Checklist*:

2.6.7a Sled Carriage Shoes
2.6.7b Sled Rails and Civil Work
2.6.7c Decelerator Station

2.6.8

Clear all discrepancies prior to next run.

2.6.9

LAB STATUS light to GREEN.

2.7 UNLOADING THE DECELERATOR

NOTE

To unload the decelerator, the sled carriage must be withdrawn so that the probes are clear of the decelerator.

2.7.1

Release hydraulic pressure on roller cage and clamp cage. Push slides of both cages out as far as possible.

2.7.2

Loosen and remove the transverse allthread rod. Do not remove maintenance straps until ready to remove allthread. This strap will prevent lower allthread from dropping to pit floor.

CAUTION

The breech bars of the lower decelerator will swing down!
The guide roller of the lower decelerator is **heavy**
and will **fall** if not supported.

2.7.3

Loosen and remove the screws holding or securing the breech bars on the roller and clamp cage and swing them out of the way.

2.7.4

The upper decelerator band(s) may now be removed by lifting them straight up. The lower decelerator band(s) will be extracted downward. It should be held and guided down to avoid jamming.

2.7.5

Check all rollers for function, clean any slag, dirt or particles accumulated in the cages. Close and secure breech bars and reinstall the transverse allthread rod IAW installation instructions.

Rev: 06.03/93

3.0 SYSTEM MAINTENANCE

3.0.1 Daily Maintenance

Most of the maintenance on the system consists of keeping it clean and rust free. The track rails are the obvious item, but they are easy to clean and inspect. More critical is the length of the bore of the propulsion cylinder, which is very difficult to inspect for cleanliness and rust. Preventative measures to keep the cylinder in proper condition are:

1. The use of dry air for propulsion.
2. Occasional cleaning and lubrication of the tow wire ropes with a dryer/lubricant such as WD-40 or equivalent.
3. Avoid long periods of system inactivity.

3.0.2 Replacement Parts

Parts that wear out or decay in operation are as follows:

- Bearing inserts or the carriage probe rollers
- Bearing inserts of the cage rollers
- Plastic shoes of the sled carriage

3.0.3

The bearings of the various rollers should be replaced as they wear out. This wear is relatively fast, especially if pulse profiles at high force levels are used.

The bearings should be replaced when diametrical clearances of more than .030 inch are observed.

3.0.4 Bearing Replacement

Bore out the old bearing on a lathe, until it is sufficiently thin to be collapsed inward with a screwdriver or chisel, then pull it out. Replace it with a new one.

3.0.5 Bearing Specifications

All bearings are powdered metal plain bearings, oil filled, SAE 841 bronze.

Dimensions:

Nominal: 1.25 ID x 1.50 OD x 2.00 long
Typical: Eagle-Picher, EP 202432

3.0.6 Plastic Shoes

The plastic shoes on the sled carriage should be replaced when they have become only .380 inch thick.

3.0.7 Track/Shoe Clearance

Track/shoe clearance (gap) on all positions should be maintained at between .04 - .06 inch (see Figure 9). The clearances should be maintained with spacers between the shoe and the mounting surface. ***Note: As shoes wear, they may be surfaced and spaced out as necessary to maintain the maximum clearance.***

Rev: 06/03/93

4.0 PERIODIC MAINTENANCE INSPECTIONS (PMI)

PURPOSE: Inspections are scheduled maintenance routines designed to verify sytem integrity. It is a preventative maintenance program to insure a high state of reliability for the laboratory; reliability in performance and safety.

4.1 VISUAL INSPECTION

The time interval for this inspection is WEEKLY. Accomplishment of this inspection is to be recorded in the HITS Labor-tory Log.

Discrepancies are to be corrected prior to any test program payload preparation.

4.1.1 Rollers: Probe and Decelerator -

Roller surfaces should be free of rust, nicks, or cracks.

4.1.2 Sled Rails -

Rails should be free of rust, nicks, cracks, or Delrin residue.

4.1.3 Wire Ropes -

Wire ropes should be free of rust. Be mindful of any fraying of the wire rope strands.

4.1.4 Reel Assembly -

Reel Assembly should be free of nicks, cracks and other surface blemishes.

4.1.5 Hydraulic Jacks -

Hydraulic Jacks end caps should be tightened snugly. Inspect for hydraulic fluid leaks.

4.1.6 Gantry -

Gantry structure is to be intact with no loose or missing parts.

4.1.6.1 - Trolley -

Trolley is free of rust, nicks and cracks. Trolley is mounted securely to I-beam and moves freely along I-beam.

4.1.6.2 - Hoist -

Hoist mechanism is clean and free of foreign matter. Chain is free of rust, nicks and cracks.

4.1.6.3 - Wheel Assemblies -

Wheel treads are free of cracks and any foreign matter that would in any way hinder the free movement of the wheels. The wheel locking mechanisms are free of rust and foreign matter and operate properly.

4.1.7 VSDI

VSDI is in place and exhibits no external damage to sensor or display unit. Target blade is in place and undamaged.

4.1.7.1

Check all cables and connectors for corrosion, bent or missing pins, cracked connector shells, fraying, cuts and missing parts.

4.1.7.2

Check that all screws, washers and nuts are in place and serviceable.

4.1.8 Allthread Rods

Allthread rods, including nuts and washers are free of corrosion, rust, and other foreign matter.

4.2 7-DAY PMI

Accomplishment of this inspection is to be recorded in the HITS Laboratory Log.

4.2.1 Compressor/Air Storage Tanks

The only launch panel connections to be made are VENT and PRESSURE for each of the propulsion systems.

4.2.1.1

Pressurize air storage tanks to 40 psi.

4.2.1.2

Close main pressure control valves.

4.2.1.3

Turn off electrical power to compressor.

CAUTION

High pressure air can cause skin-penetration injuries.

4.2.1.4

Refer to Figure 10. Slowly open manual pressure relief valves 1/2-turn. Do this for the compressor and each air storage tank.

4.2.1.5

After compressor/air storage tanks have completely vented, close all manual pressure relief valves.

4.2.2 Decelerator Cages, Hydraulic

Operate each decelerator cage. Insure that each cage closes and opens properly: cage slides extend and retract smoothly with no external interference.

4.2.3 Safety Switch, Launch Station

Refer to Figure 11. Apply power to SAFETY light assembly. Release light assembly relay by manually retracting SAFETY pin. GREEN light should change to RED and Klaxon should sound-off. Manually extend SAFETY pin to reactivate light assembly relay. RED light OFF/Klaxon OFF, GREEN light on. Remove power to SAFETY light assembly.

4.2.4 Sled Rails and Wire Ropes

Upper and lower, non-painted surfaces of sled rails are to be cleaned and lubricated with a dryer/lubricant such as WD-40 or equivalent. Wire ropes are to be cleaned and lubricated with a dryer/lubricant such as WD-40 or equivalent.

4.2.5 Propulsion Cylinders and Controls

Cylinders and control mechanisms are to be clean and dust free. Inspect for and repair surface blemishes.

4.2.6 Decelerator Station Columns

Columns are to be clean and dust free. Inspect for and repair surface blemishes.

4.3 30-Day PMI

Accomplishment of the inspection is to be recorded in the HITS Laboratory Log.

4.3.1 PROPULSION SYSTEM CONTROLS

4.3.2 Auxiliary Propulsion System

Connect Auxiliary controls (grey) to launch panel.

4.3.3

Open auxiliary main pressure control valve.

4.3.4

Pressurize air storage tank to 20 psi.

4.3.5

On launch control panel, set DELAY for 5 seconds.

4.3.6

Initiate launch sequence; activate FIRE switch at Lab Manager's command. Lock FIRE switch at completion of test.

4.3.7 Main Propulsion System

Connect Main controls (yellow) to launch.

4.3.8

Open main main pressure control valve.

4.3.9

Pressurize air storage tanks to 20 psi.

4.3.10

On Launch control panel, set DELAY for 5 seconds.

4.3.11

Initiate Launch sequence; activate FIRE switch at Lab Manager's command. Lock FIRE switch at completion of test.

4.3.12

Safety propulsion system: close both main pressure control valves; turn off air compressor; vent all storage tanks IAW Section 4.2.1.4 and Section 4.2.1.5.

Rev: 06/03/93

5.0 CALIBRATION/ALIGNMENT PROCEDURES

5.0.1 PURPOSE

5.1 Probe Alignment, Upper

5.1.1 Alignment in the Pitch Plane: (in the decelerator area with payload installed and secured for test).

Ascertain that the upper probe length configuration is correct, and that the inner and outer probe casings are parallel. *See Section 5.6.*

5.1.2

Insure that all set screws and adjustment nuts are set and fully tightened.

5.1.3

Refer to Figure 12. Partially loosen upper probe's angle bracket mounting bolts but do not remove.

5.1.4

Insert a 1/8 inch thick spacer between the probe guide shoe of the upper probe and the decelerator guide-way.

5.1.5

Clamp the probe to the guide-way.

5.1.6

Tighten and torque all screws on the brackets; proceed to Section 5.4, Probe alignment, Check.

5.2 Probe Alignment, Lower

5.2.1 Alignment in the Pitch Plane: (in the decelerator area with the payload installed and secured for test).

5.2.2

Refer to Figure 13. Partially loosen lower probe attach point mounting bolts but do not remove.

5.2.3

Clamp the lower probe to the guide-way (DO NOT USE SPACERS).

5.2.4

Tighten and torque all lower probe attach point mounting bolts; proceed to Section 5.4, Probe Alignment, Check.

5.3 Probe Alignment, Yaw Plane

5.3.1 Upper Probe: (with or without payload installed).

5.3.2

Refer to Figure 12. Partially loosen all upper probe angle bracket-to-carriage cross member mounting bolts but do not remove.

5.3.3

Clamp the probe roller cage to the lateral guide-way, with a 1/8 inch spacer, at approximately 3 inches past the tapered section.

5.3.4

Make sure that the lateral clearance of the sled carriage shoes to the rails is all on the opposite side of the probe lateral guide shoe by pushing the carriage sideways into the rails.

5.3.5

Tighten and torque all screws. Proceed to Section 5.4, Probe Alignment, Check.

5.4 Probe Alignment, Check

5.4.1 Upper Probe, Pitch

After unclamping and removing the spacer used during alignment, the upper probe should drop down to touch the decelerator guide-way or just clear it. Ideally, the upper probe should clear the guide-way surface by .0625 inch maximum.

5.4.2

Slide the carriage aft until the upper probe is in the tapered entry of the guide-way. The upper probe may follow the ramp down for a vertical distance no greater than .032 inch.

If a greater displacement occurs, check that the sled carriage rear shoes are down on the rail. If they are lifted up, supply additional weight to the back of the carriage. If that cannot be done, make sure that the lower rear sled carriage shoe clearances are such that the probe is not allowed to droop beyond the .032 inch nominal allowable. If neither solves the problem, repeat the upper probe alignment procedure using a thicker spacer underneath the probe guide shoe when clamping the probe to the guide-way, and utilizing the fine-align procedures of Section 5.5.

5.4.3 Upper Probe, Yaw

Slide carriage aft and observe entry into the decelerator guide-way. A misalignment of .063 inch towards the ramped lateral guide is the maximum allowable.

5.4.4 Lower Probe, Pitch

After unclamping the lower probe, it should drop away some and clear the decelerator guide-way. A clearance of up to .130 inch is normal for the lower probe.

5.4.5 Lower Probe, Yaw

The lower probe is not readily aligned when in the retracted position, i.e when the securing screws are at the mid-longeron position. Some alignment is possible by using shims between it and the longerons in the forward area underneath the front cross member of the sled. If serious misalignment exists, find the cause by checking the side thrust shoes of the carriage, or check for bent or mis-installed longerons.

Yaw plane alignment when the lower probe is mounted in the full forward position is accomplished by shimming only.

5.5 Probe Alignment, Upper Fine-Align

Refer to Figure 14. Some minor misalignment can be compensated by moving the roller head up or down (+/- .025 inch maximum).

5.5.1

After clamping the upper probe to the guide-way, loosen the roller head mounting bolts enough to allow adjustment.

5.5.2

Make the necessary adjustments in increments of .0625 inch. Insure that the roller head is not cocked but sits square with the guide-way.

5.5.3

Tighten roller head mounting bolts, unclamp probe and recheck probe alignment.

5.5.4

Torque roller head mounting bolts to 85 ft. lbs.

5.6 Probe Alignment, Variable Length

Refer to Figure 15. This alignment is relatively self-explanatory. It is very important to notice that the maximum length of the probe requires a minimum overlap of eight inches of the outer probe casing to the inner probe casing.

5.6.1

Overall Length (OL) equals 126.19 -- is probe maximum extension.

5.6.2

To adjust the upper probe length, remove the ten 3/8' holokrome allen head bolts located at the center point of the probe assembly.

5.6.3

Loosen, but do not remove, the ten inner mounting bushings.

5.6.4

Loosen, but do not remove, the four 5/16" holokrome allen head bolts and retaining nuts located top and below of upper probe center joint.

5.6.5

Remove upper and lower support plates located within upper probe center joint.

5.6.6

Adjust the inner probe casing to the desired length. Notice that the threaded holes along each side of the inner probe casing allow for adjustments in 2" increments.

5.6.7

Reinstall center joint support plates. Do not tighten the four center joint plate bolts at this time.

5.6.8

Partially install the ten 3/8" holokrome allen head bolts. Install each bolt only enough to sufficiently support the inner probe casing.

5.6.9

Horizontally center the inner probe casing within the outer probe casing.

5.6.10

Tighten the inner mounting bushings such that they contact but not move the inner probe casing. When satisfied that the inner probe casing is horizontally centered, tighten the inner mounting bushings (alternating one bushing per side) to secure inner probe casing.

5.6.11

Tighten and torque the ten 3/8" holokrome allen head bolts to 90 ft/lbs.

5.6.12

Tighten the center support bolts snugly, then snug down the center support bolts retaining nuts.

APPENDIX
A

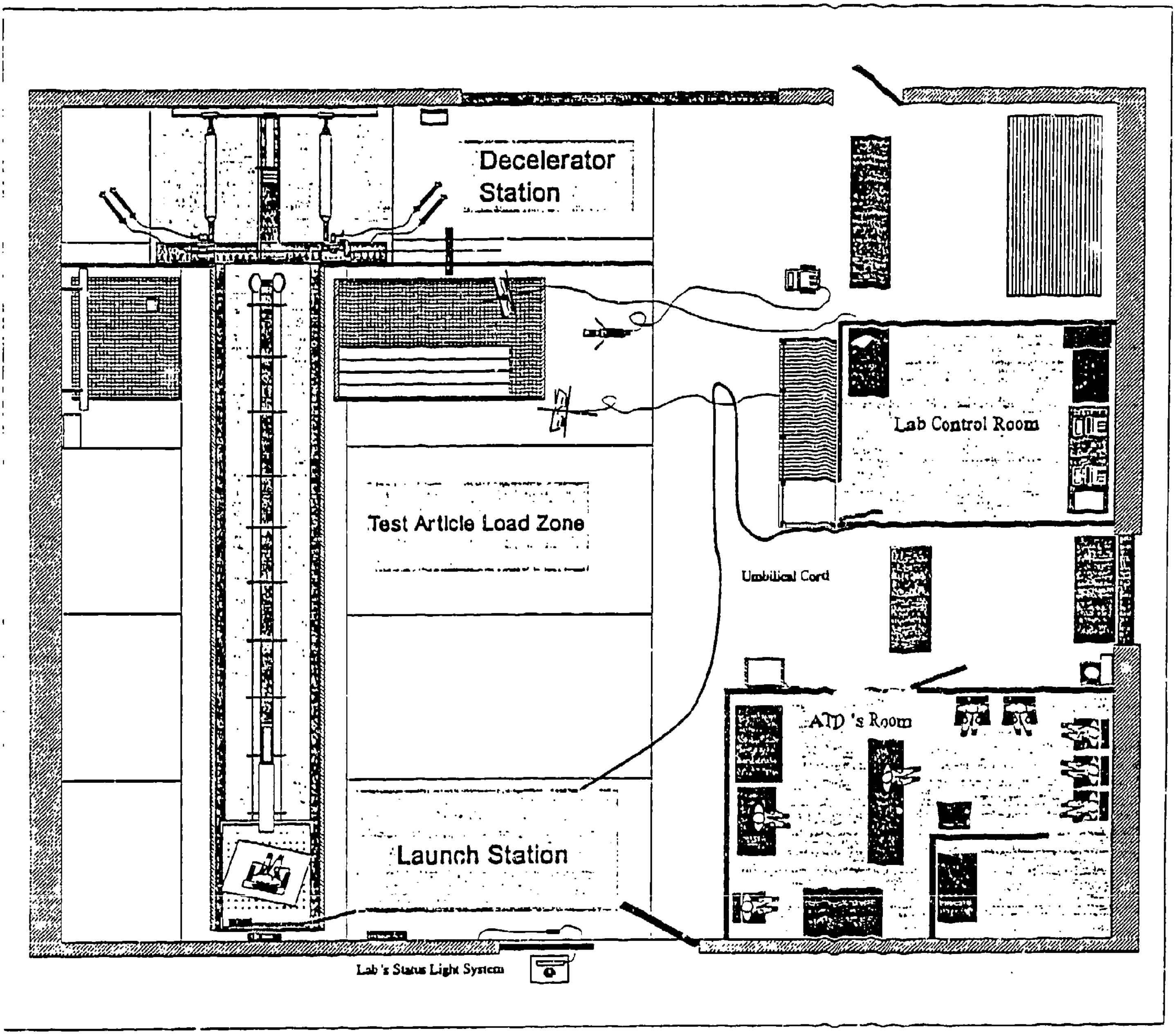
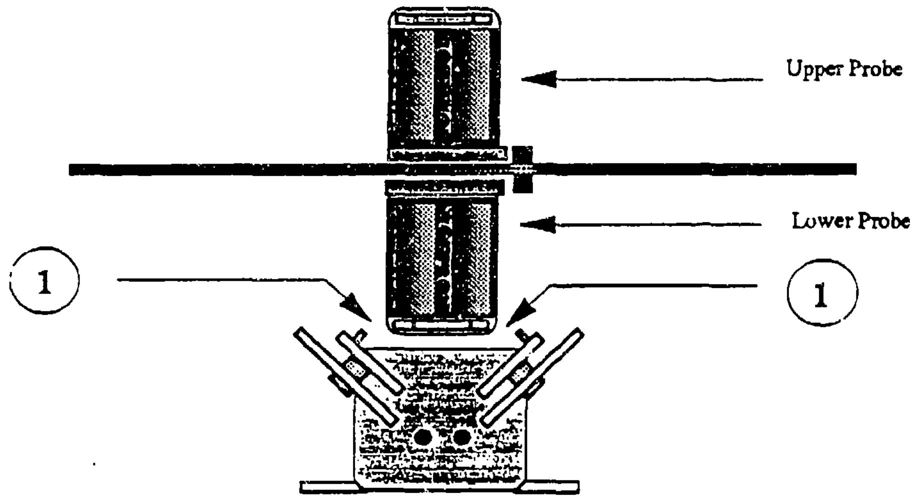


Figure 1: Laboratory Overview



1 Observe here for proper probe -to- reel assembly clearance.
Minimum clearance: 0.5 inches.

Figure 2: Forward View, Probe vertical and horizontal positioning.

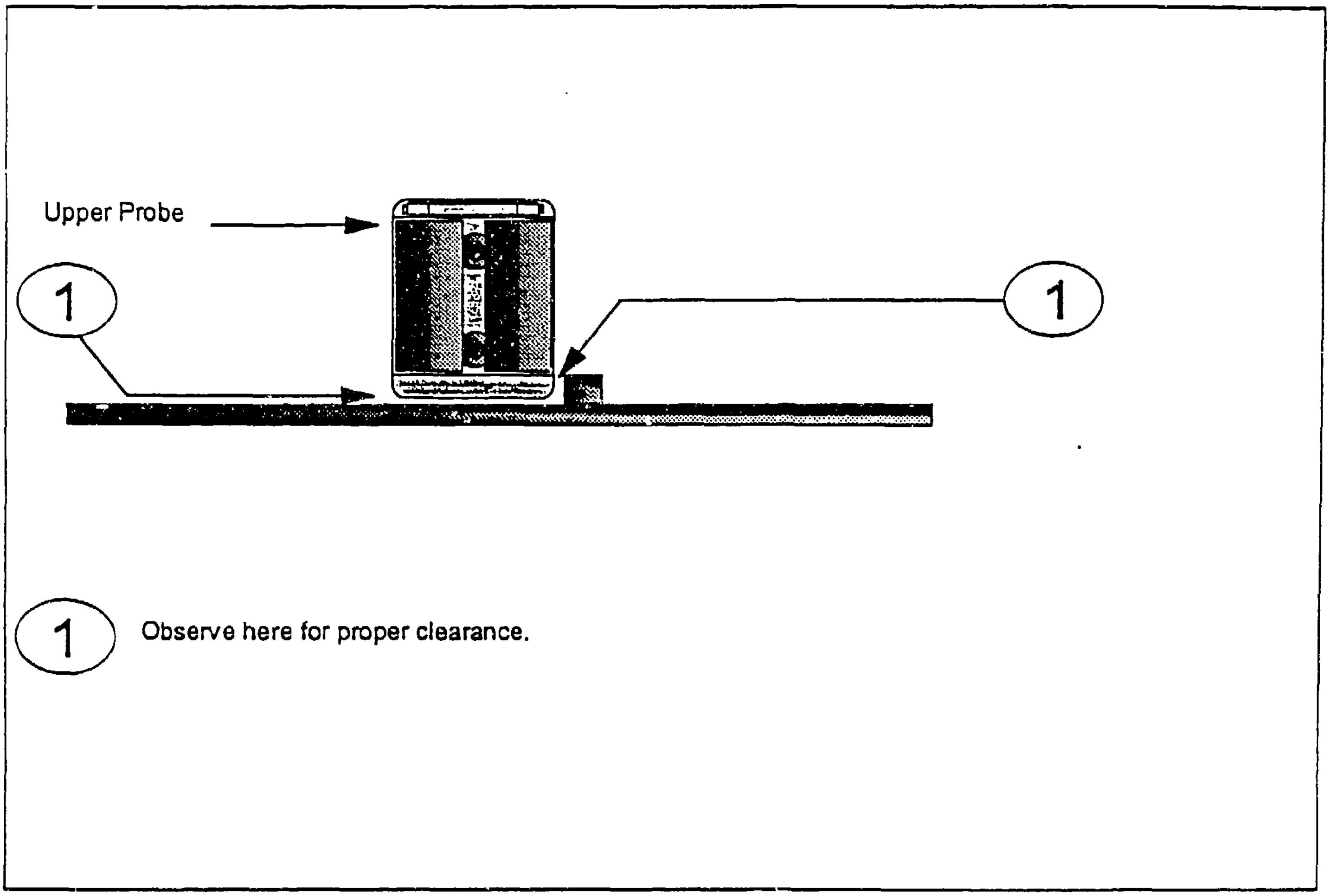


Figure 3: Upper Probe Clearance, pitch and yaw.

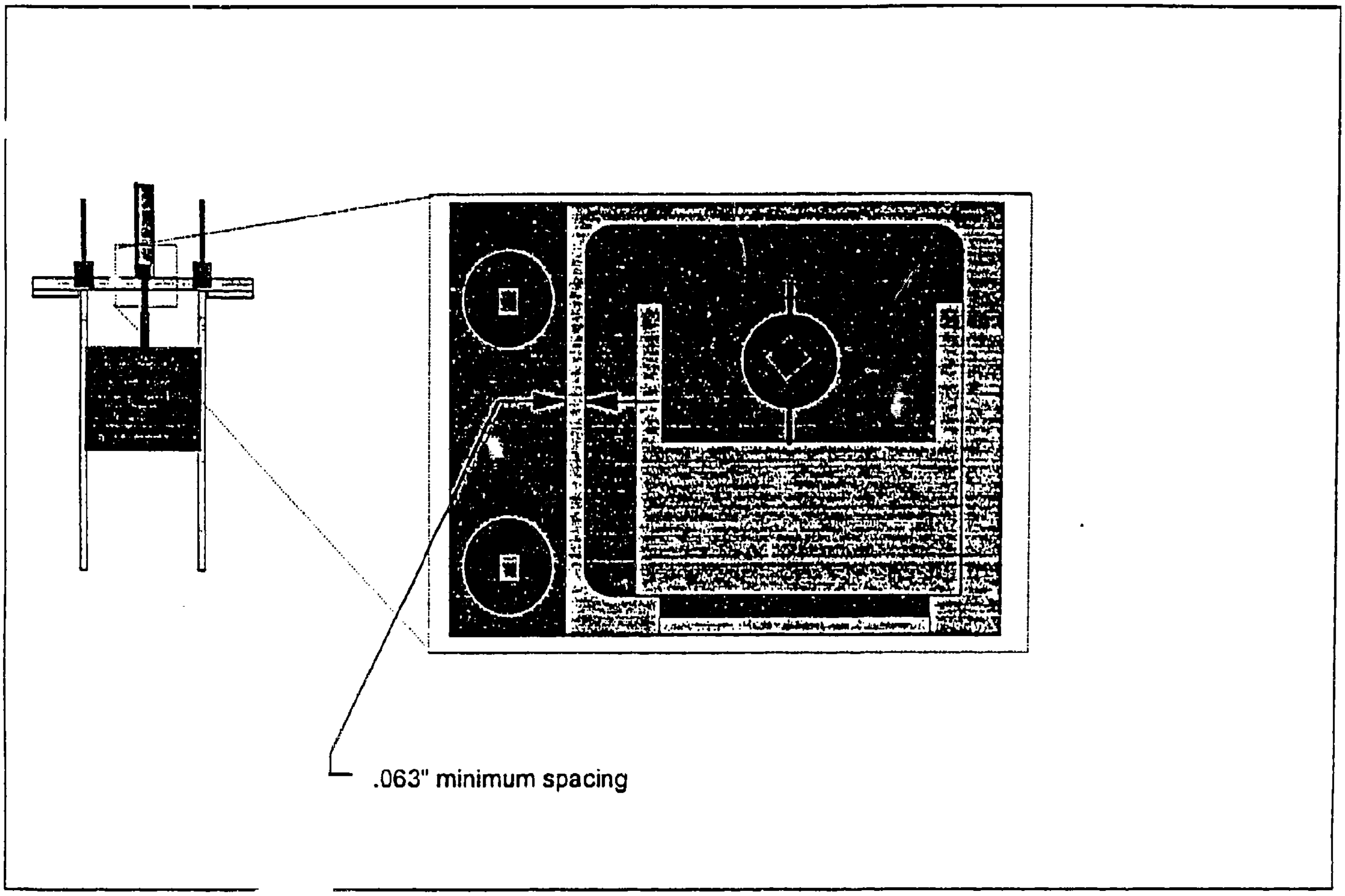


Figure 4: Upper P[illegible] clearance.

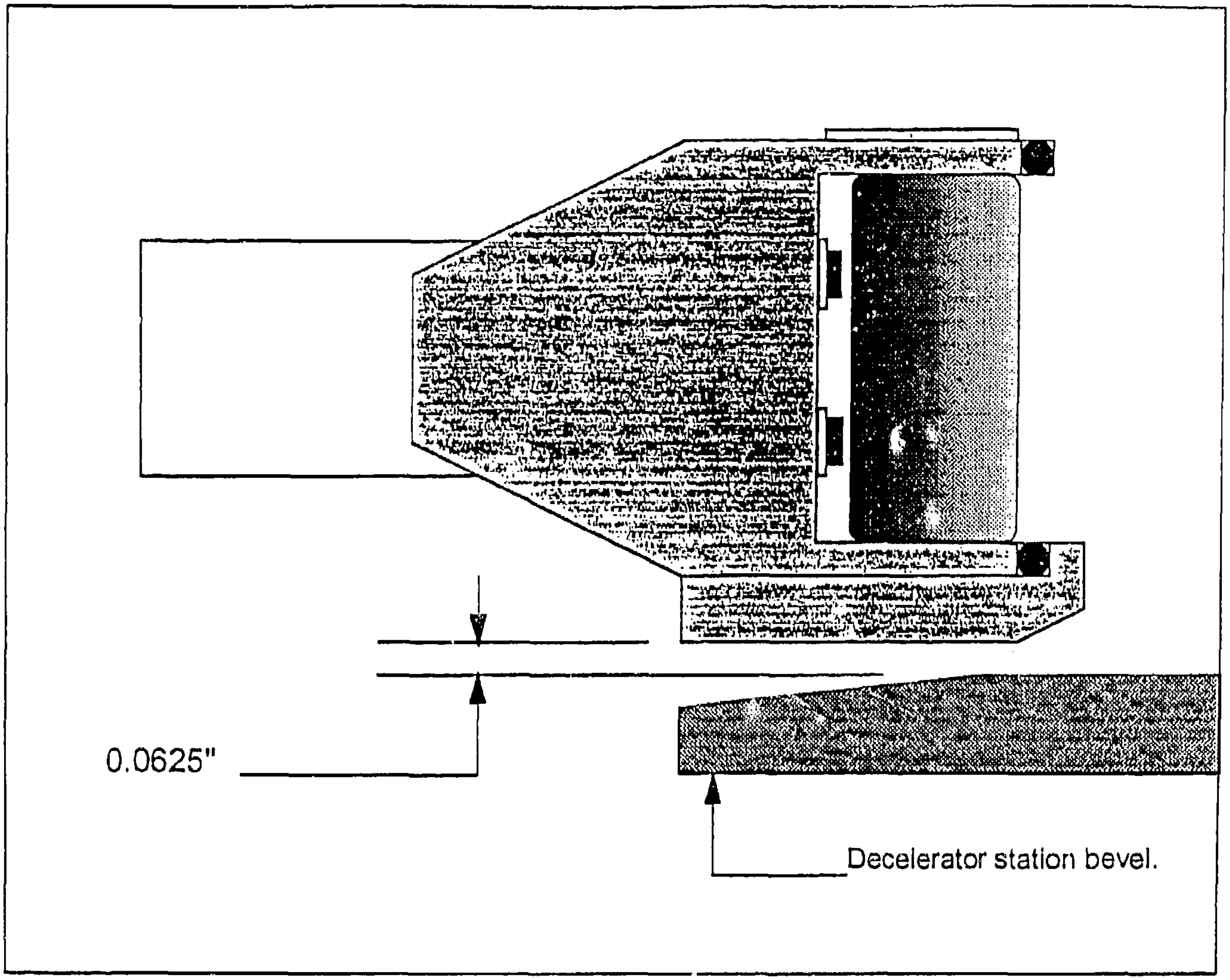


Figure 5: Upper Probe Alignment - - minimum allowable pitch.

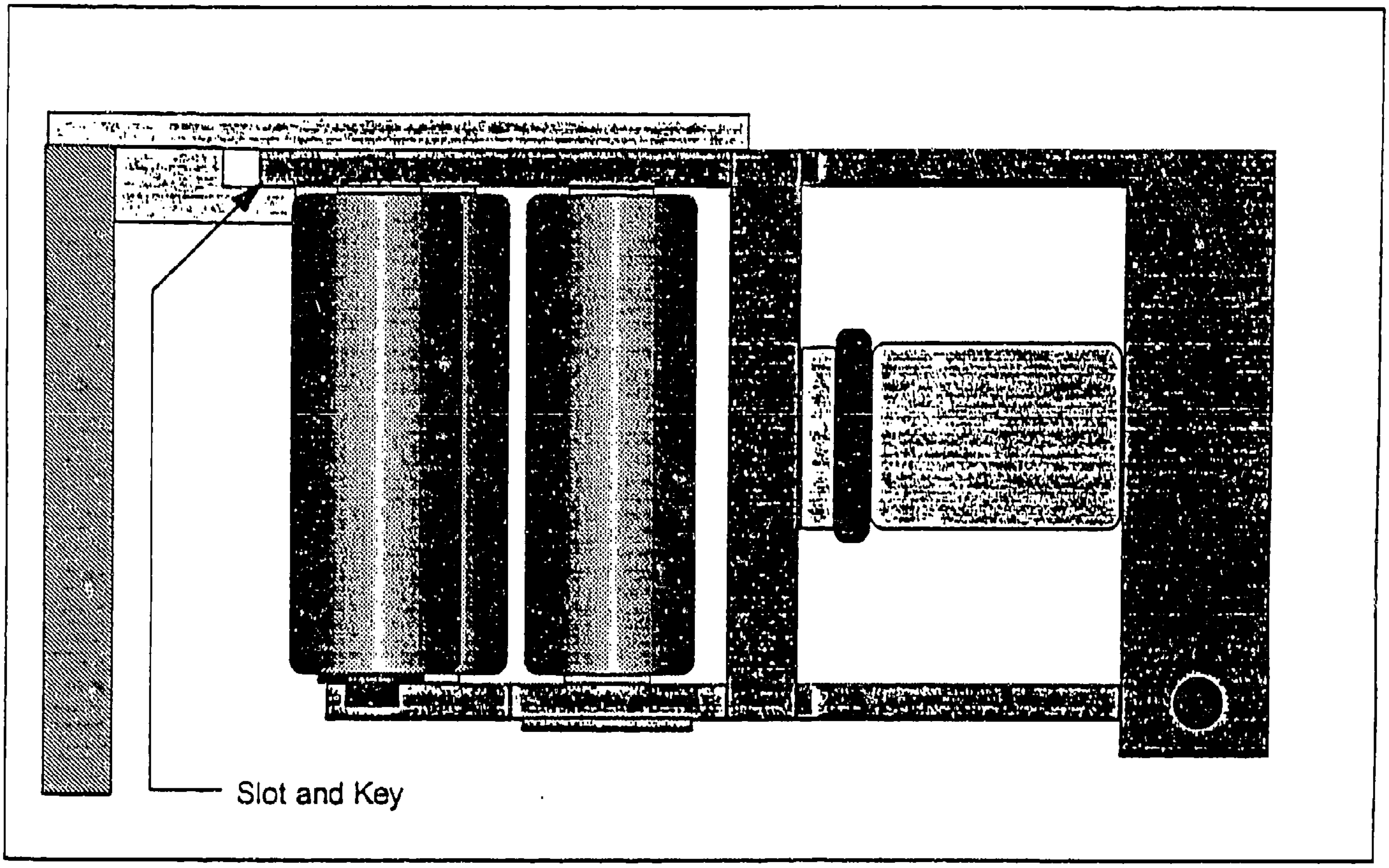


Figure 6: Lower Decelerator - - lateral adjustment

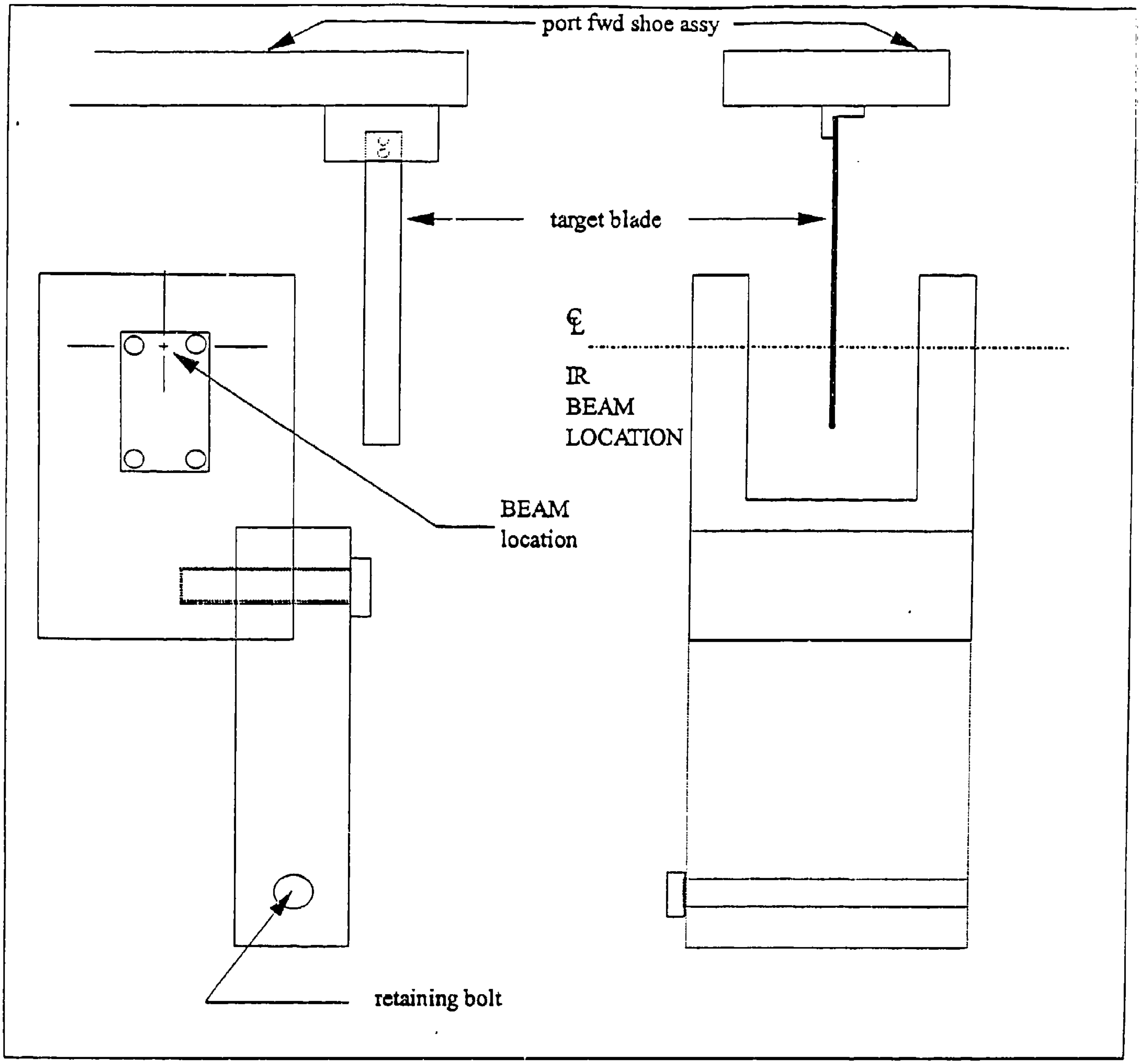


Figure 7: VSDI Alignment

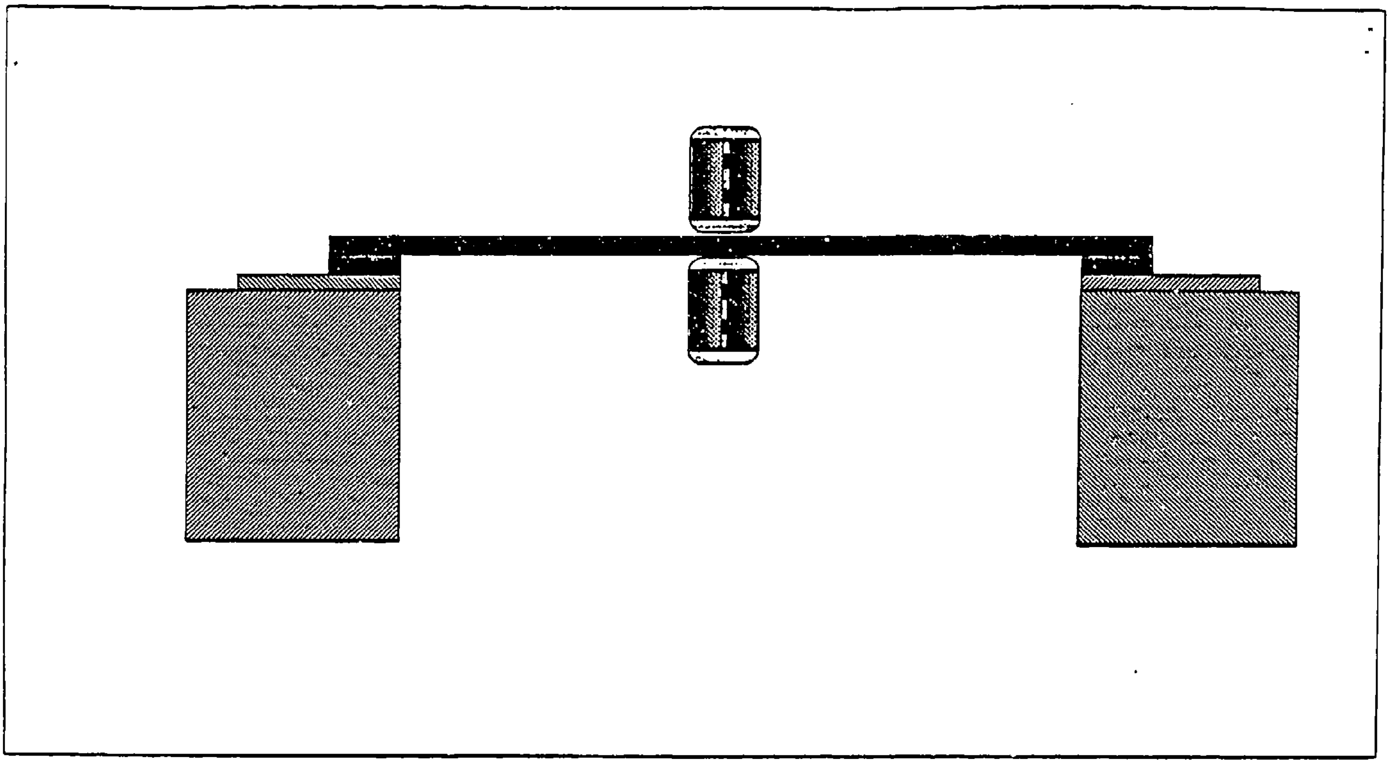


Figure 8: Auxiliary Probe Alignment

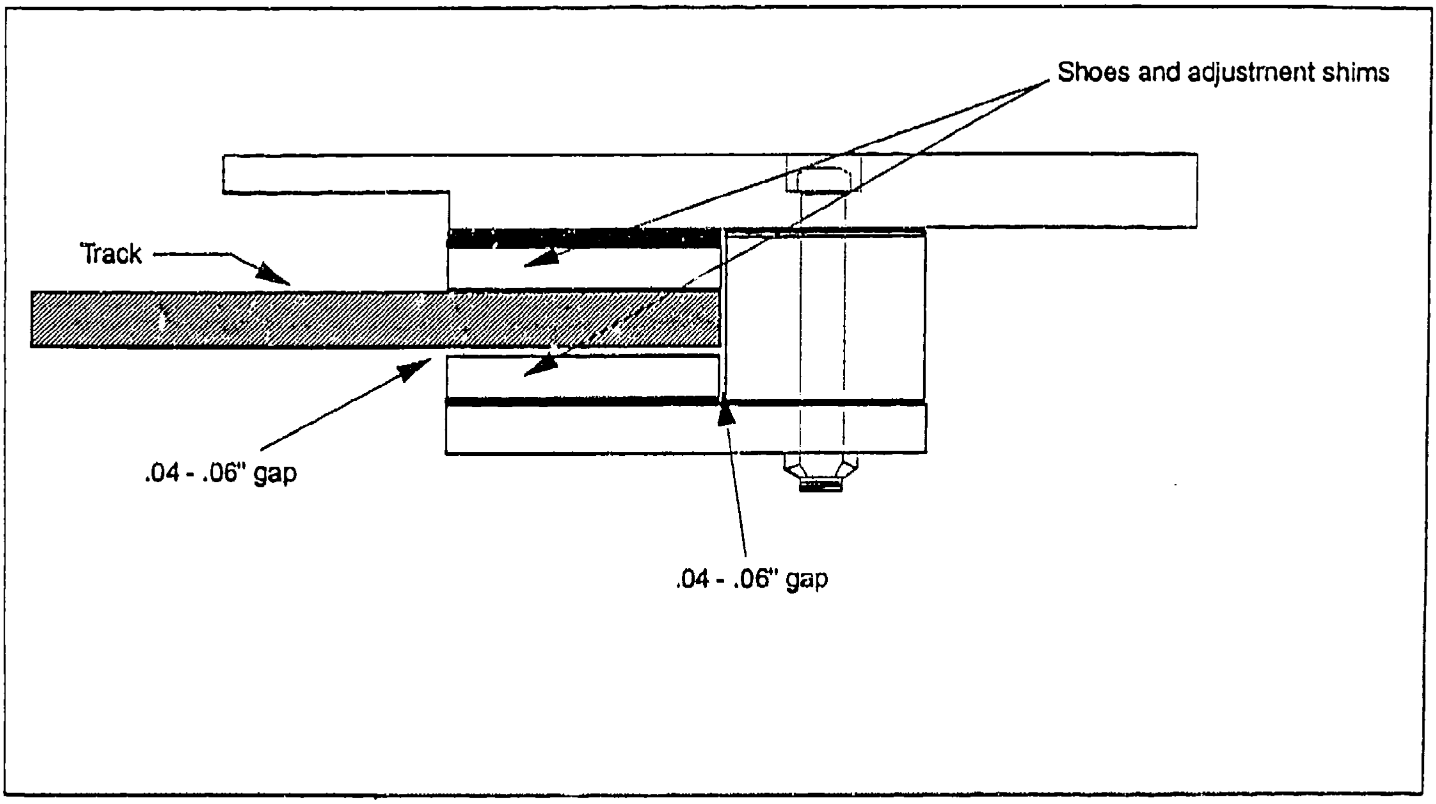


Figure 9: Upper/Lower Sled Carriage Shoes

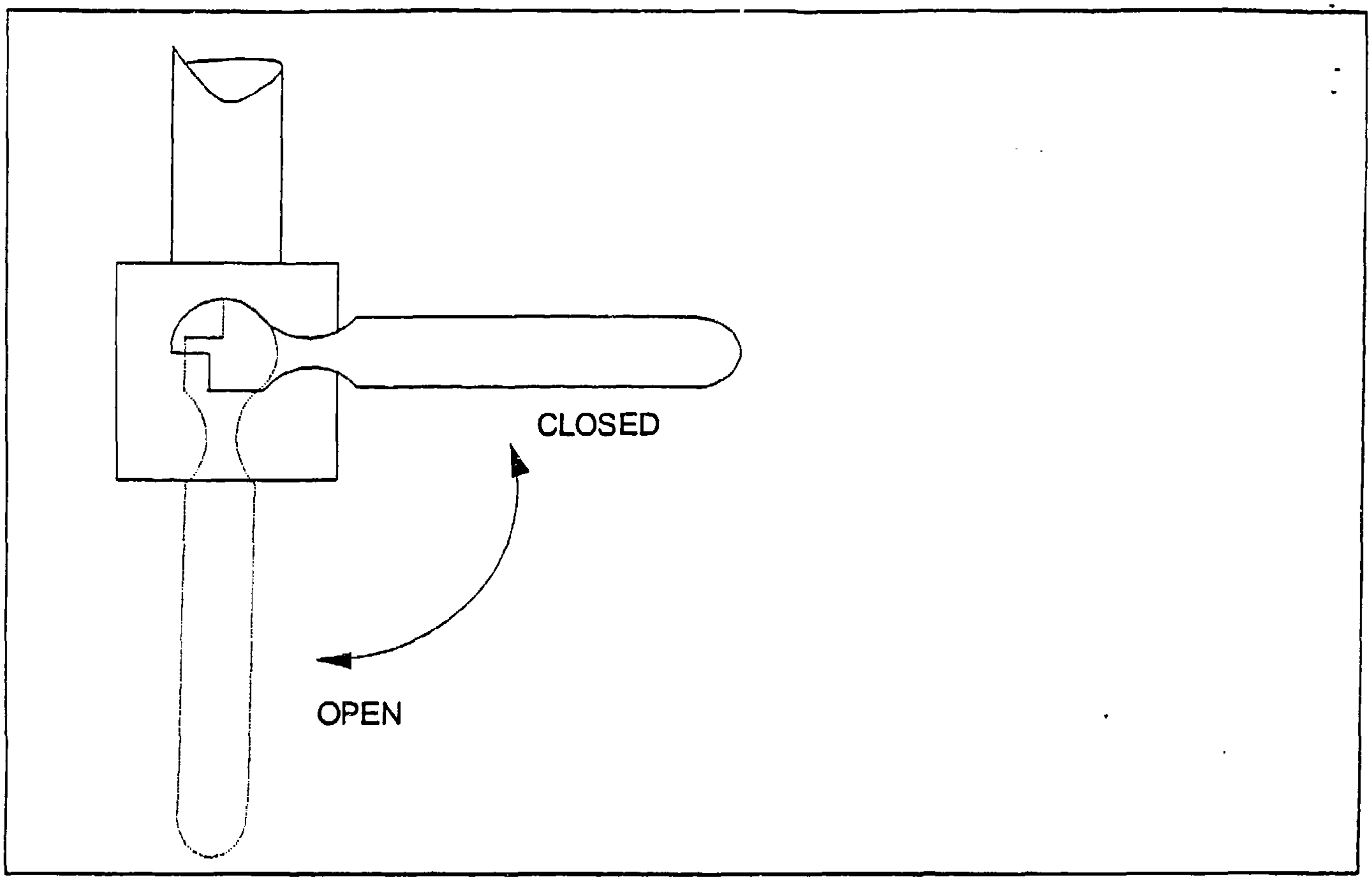


FIGURE 10: Relief Valve, Manual, Air Tanks

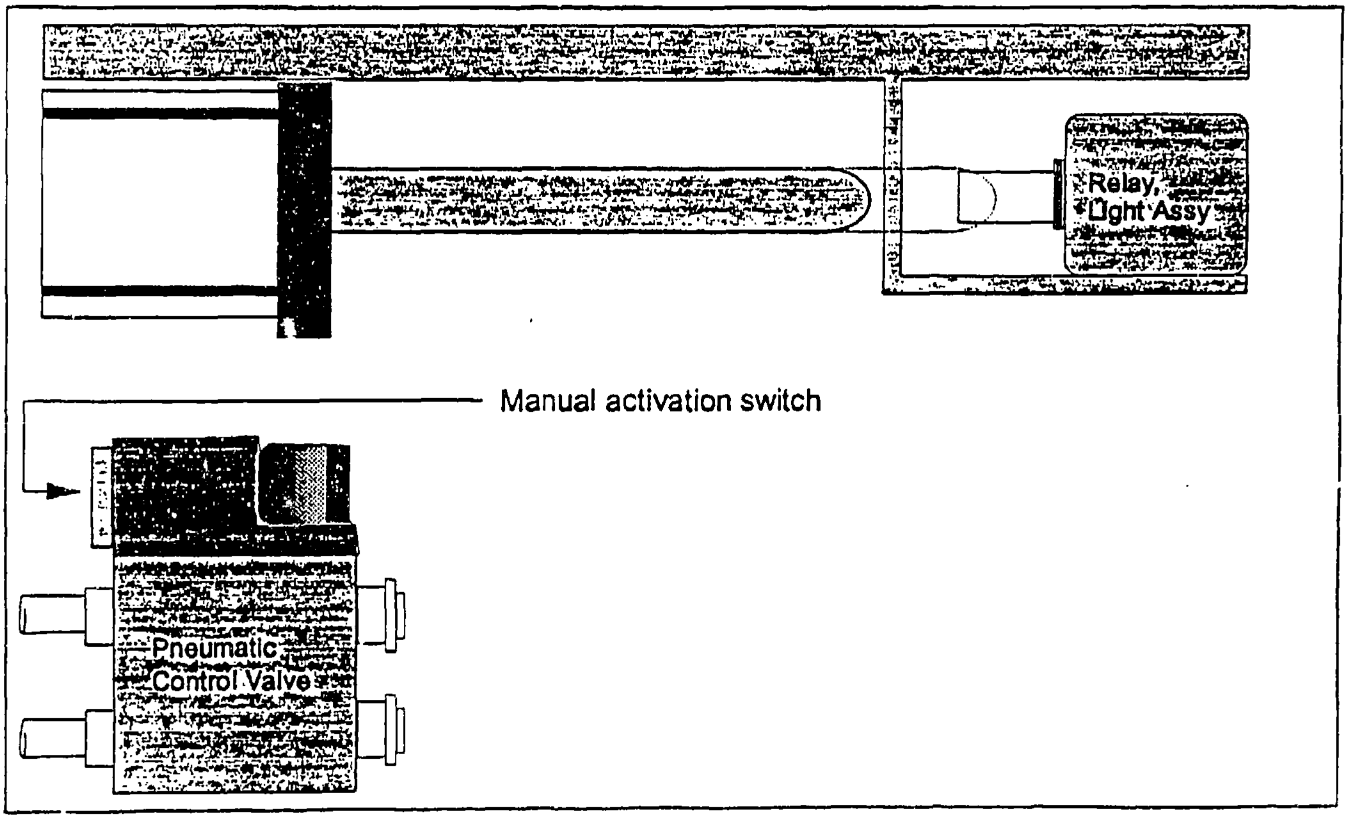


FIGURE 11: SAFETY PIN, Launch Station

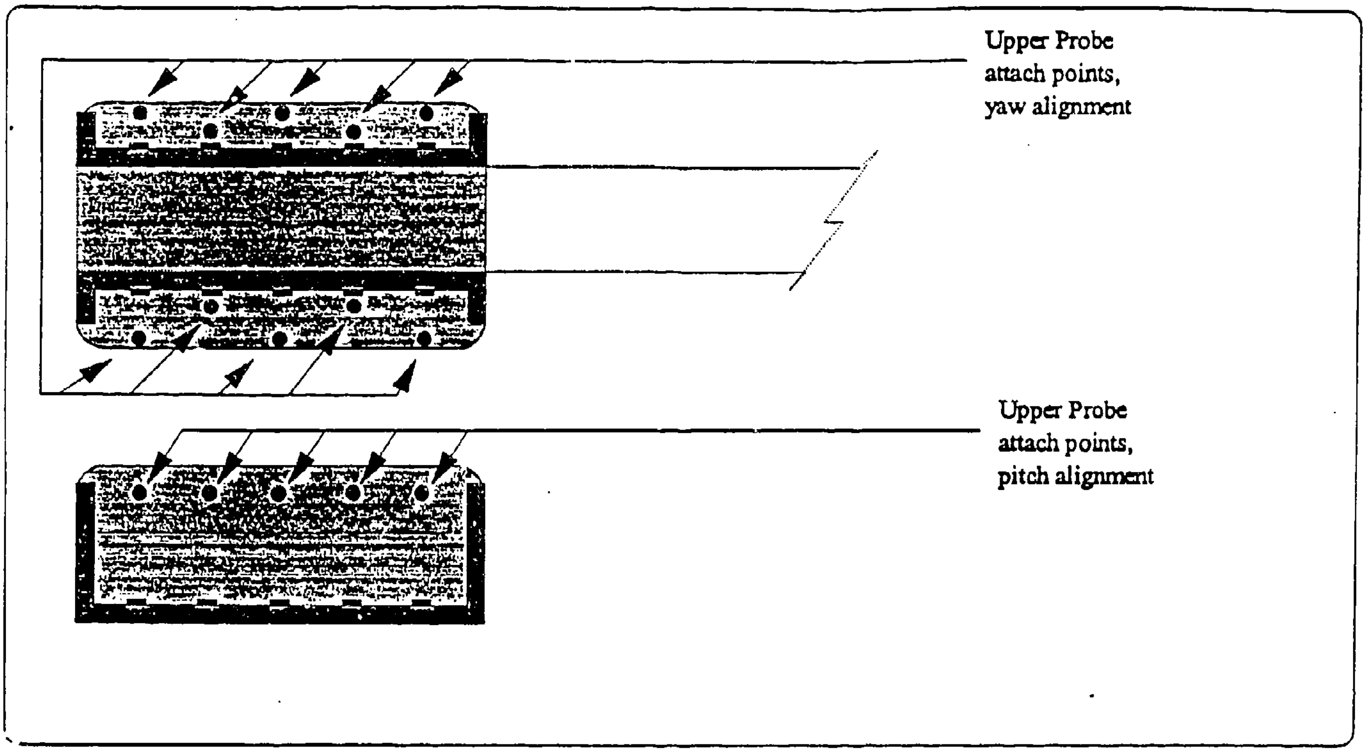


FIGURE 12: Upper Probe Attach Point

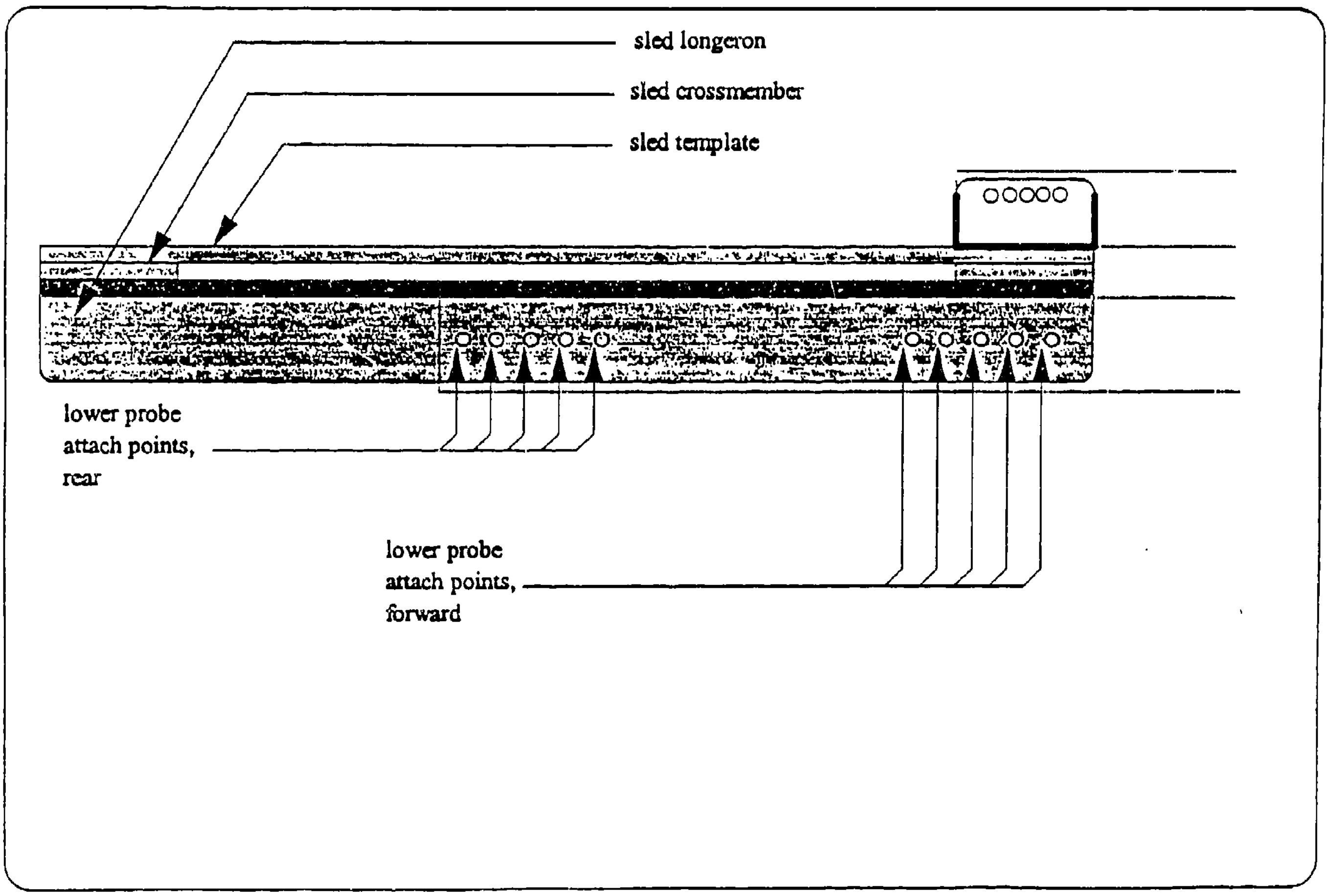


FIGURE 13: Lower Probe Attach Points

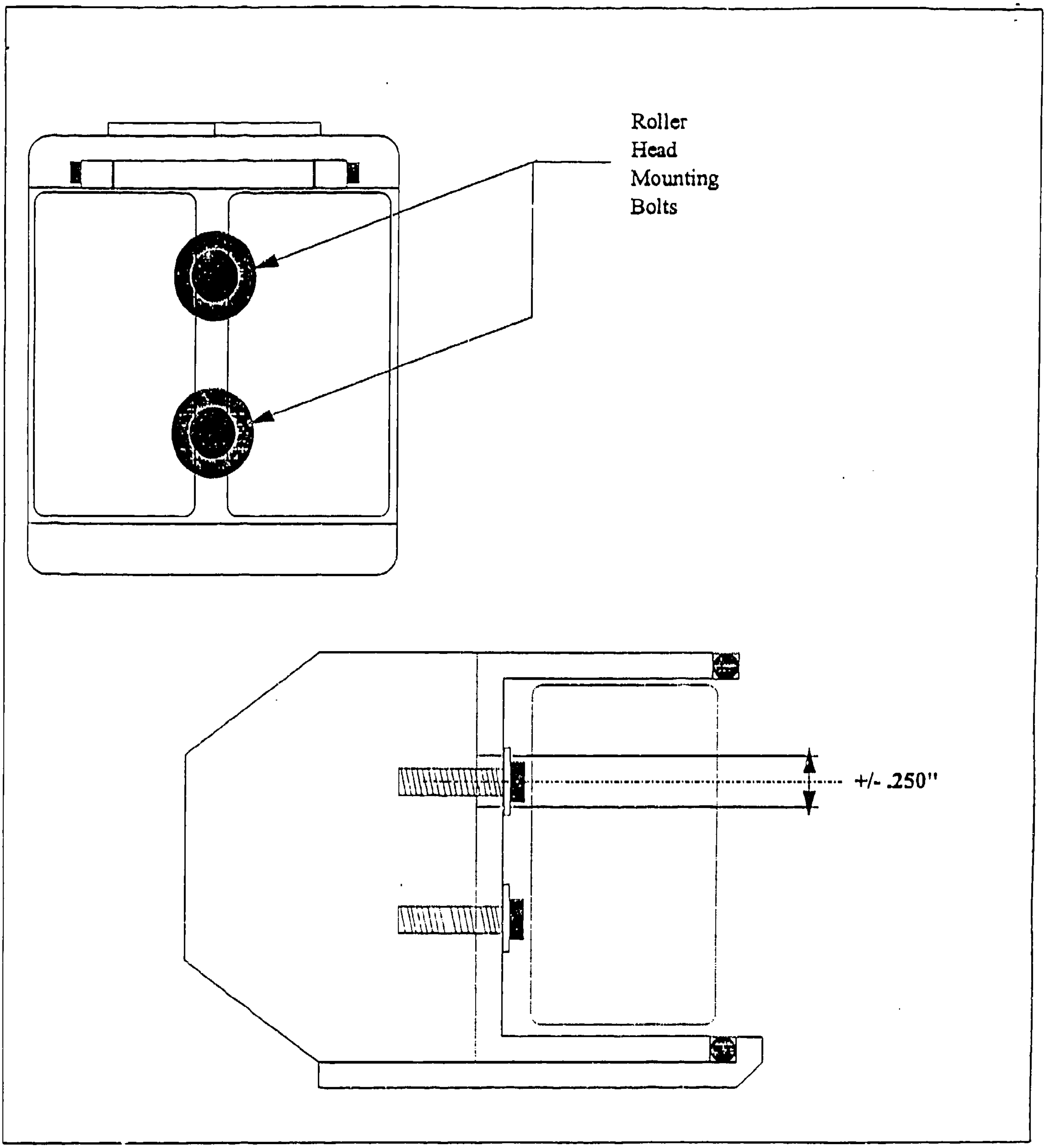


Figure 14: Probe Head Fine Align

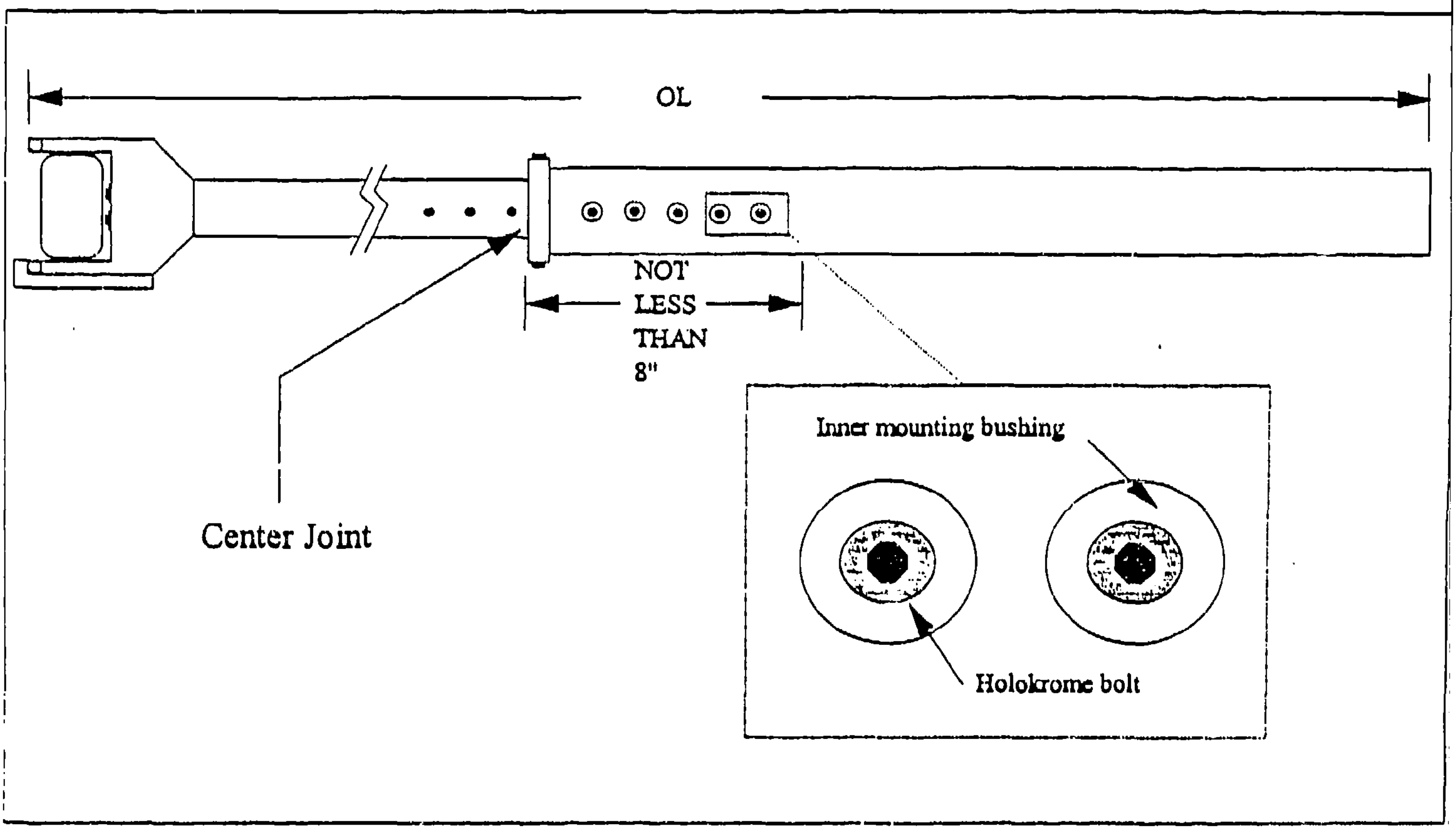


Figure 15: Probe Alignment, Variable

APPENDIX B

An Overview of Procedures in the Impact Dynamics Laboratory

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June 1993

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The Wichita State University

Table of Contents

1.) List of Figures and Tables

2.) Introduction

The impact dynamics laboratory is intended to assist industry and researchers in the testing of articles that need to demonstrate an ability to withstand impact loads in their working environment. Much of the emphasis is on the testing of aircraft seats that must demonstrate compliance with federal regulations, but the facility is well suited to the testing of any product where impact loading and performance is of concern.

The facility uses a horizontal impact test sled. The sled is accelerated up to the necessary impact velocity and then decelerated in a manner that represents the desired impact loading. This is known as a decelerator type sled. The decelerator system consists of a set of rollers that are used to plastically deform a series of steel straps. By varying the configuration of the straps the impact loading can be varied. Included in this report are the methods used to tune the decelerator to provide a desired impact loading.

The bulk of the work in the lab has centered on the development of deceleration pulses and the methods of developing those pulses. The restraining system straps were statically tested to attain their force versus displacement characteristics. A desired deceleration pulse given as g's versus time can be integrated to get a force versus displacement curve. The force versus displacement curve for the pulse is then matched by a force versus displacement curve from a combination of straps. These methods that have been developed over time are the result of part science and part experience. The procedures used to create a deceleration pulse along with the procedures necessary to perform a test are presented in this report.

Development of the laboratory began in September of 1990 when the sled was installed. The developmental work in the lab began with static testing of the restraining system straps, then moved into development of deceleration pulses to meet FAA requirements, and has now included the successful completion of several FAA certification tests of aircraft seats.

The impact dynamics laboratory is located at the Wichita State University, Wichita, Kansas and is part of the National Institute for Aviation Research.

3.) Overview of the Sled-Decelerator System

Before going into an in-depth explanation of how to create a deceleration pulse it is necessary to develop an understanding of the components that make up the sled system and how they function. This will also assist in explaining some of the nomenclature that will be used throughout the report.

The system can be thought of as having four main components. These components are the sled, the propulsion system, the data collection system, and the restraining system. All of these components perform together to form the horizontal impact test sled.

3.1.) The Sled

The sled carries the payload during the impact test. The sled consists of two probes used to contact the straps, a template plate for mounting the payload, a set of plastic shoes that ride the rails, and an interface box for the umbilical cable. The sled is shown below in figure 3.1.1.

The sled template is the area of the sled where the test article is mounted. The template has a 6" by 6" hole pattern across its usable area.

The probes, which contact the straps, are located at the front of the sled. There is an upper and lower probe on the sled. There is a separate restraining system for each probe. Both probes function in the same manner, so the upper and lower systems are interchangeable.

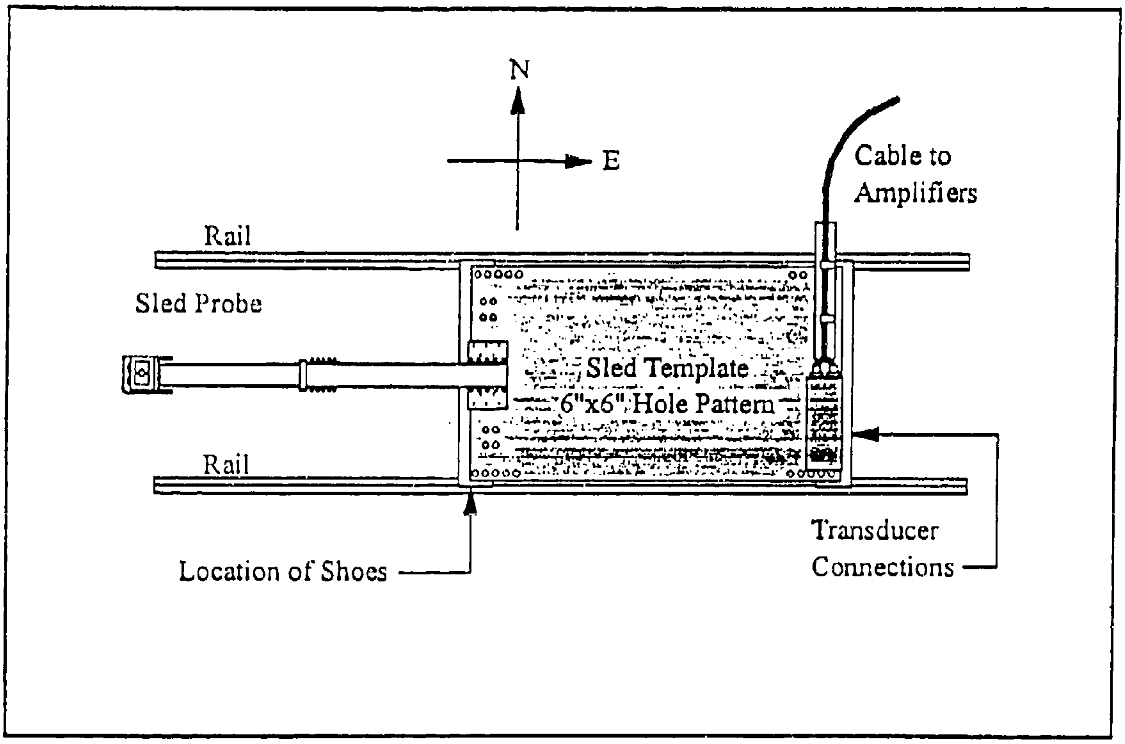


Figure 3.1.1
Impact Sled

Located at the Southeast corner of the sled is the umbilical interface box, or what is called the "blue box", which is where transducers used during the test are connected to the data system. Each connection on the box corresponds to a data channel that has its own signal amplifier.

At the four corners of the sled are the shoes. The shoes are small pads of Delrin plastic upon which the sled rides.

3.2) The Propulsion System

The propulsion system consists of an air compressor, a series of air tanks for storing the compressed air, a piston and cable assembly, a series of pneumatic valves to regulate air flow to the piston, a safety pin to lock the sled into the launch position and a control panel. There are two separate systems. One, the primary propulsion system has a 7.5" diameter piston and the other, the secondary propulsion system, has a 4.25" diameter piston. The sled propulsion system is shown in figure 3.2.1. Only one of the pistons can be used at a given time.

The air compressor is located in the pit on the South side of the track. It feeds compressed air to the tanks of the propulsion system being used. It also supplies air to the valve controls. The compressor is turned on and off through an electrical box located on the South wall of the pit that the compressor is located in. The compressor and its on/off switch are shown in figure 3.2.1.

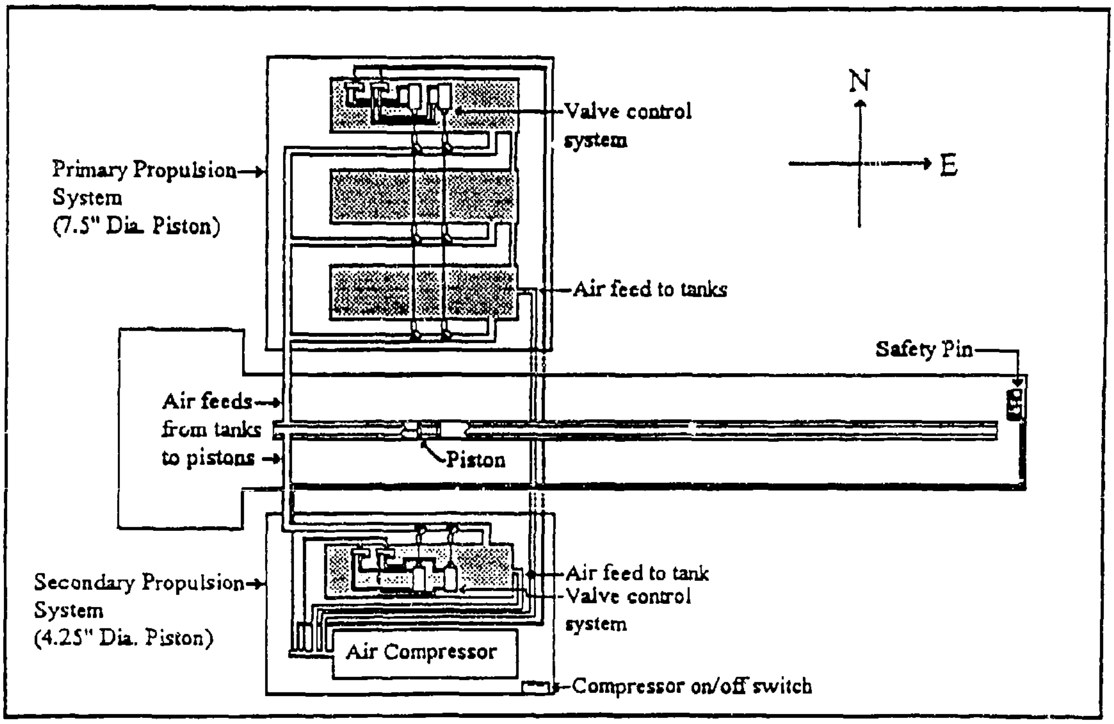


Figure 3.2.1
Sled Propulsion System

The air tanks for each of the systems are located in the pits on either side of the track. The tanks for the primary propulsion system are in the pit on the North side of the track and the tank for the secondary system is located in the pit that contains the air compressor, which is on the South side of the track. The three tanks for the primary system are connected in parallel. There is a pressure transducer on the tank for the secondary system and on one of the tanks for the primary system. The transducers are connected to a digital meter that displays system pressure. The meter is located in the control room. The location of the tanks can be seen in figure 3.2.1.

The pneumatic control valves are located on top of the northern most tank for the 7.5" piston system and on top of the tank for the 4.25" piston system. There are two valves per system, the firing valve and the safety valve. The safety valve, the one toward the West end of the tank must be opened before the sled can be fired. The firing valve, the one toward the East end of the tank, is controlled by the fire button. This valve is open for a predetermined time. The time this valve is open determines the speed the sled will attain at the impact position. The location of these valves is shown in figure 3.2.1 and the location of the switches that control the valves are shown in figure 3.2.3.

The piston and cable assembly runs between the rails in the sled trench. There are two pipes. The top one is for the secondary system and the bottom one is for the primary system. The piston starts at the West end of the track before a run. Air pushes the piston down the pipe toward the East end of the track when both sets of valves on the tanks are opened. The result is the sled being pulled toward the impact

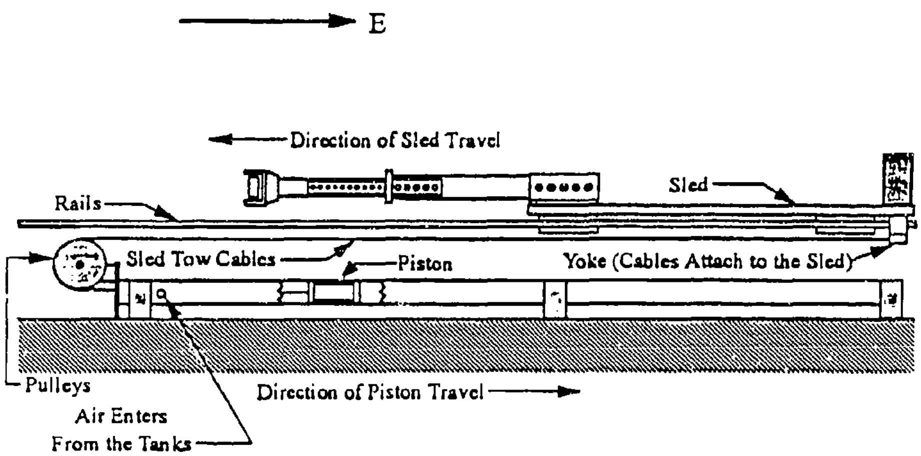


Figure 3.2.2
Sled-Propulsion System Connection.

position. The connection of the cables to the sled is called the yoke. Both of the cables are connected into the yoke that bolts onto the bottom of the sled. Where the cables enter into the pipes there is a set of pulleys. There are two pulleys that guide the cables as they change direction and enter the pipe. The connection between the sled and the piston and cable assembly is shown in figure 3.2.2.

The propulsion system is run by a panel located in the control room of the lab. This control panel allows the propulsion system to be pressurized, vented, and allows the sled to be fired. The control panel is shown in figure 3.2.3.

The main power switch controls all power to the panel. No operations can be performed if the main power switch is not in the on position. The orange light located above this switch will be on if the switch is in the on position.

The vent/pressurize switch injects air into the tanks in the pressurize position and removes air from the tanks in the vent position. This switch has a neutral position in the center.

The tank pressure dial on the panel is not currently used. Tank pressure is read off a digital display to the right of the control panel.

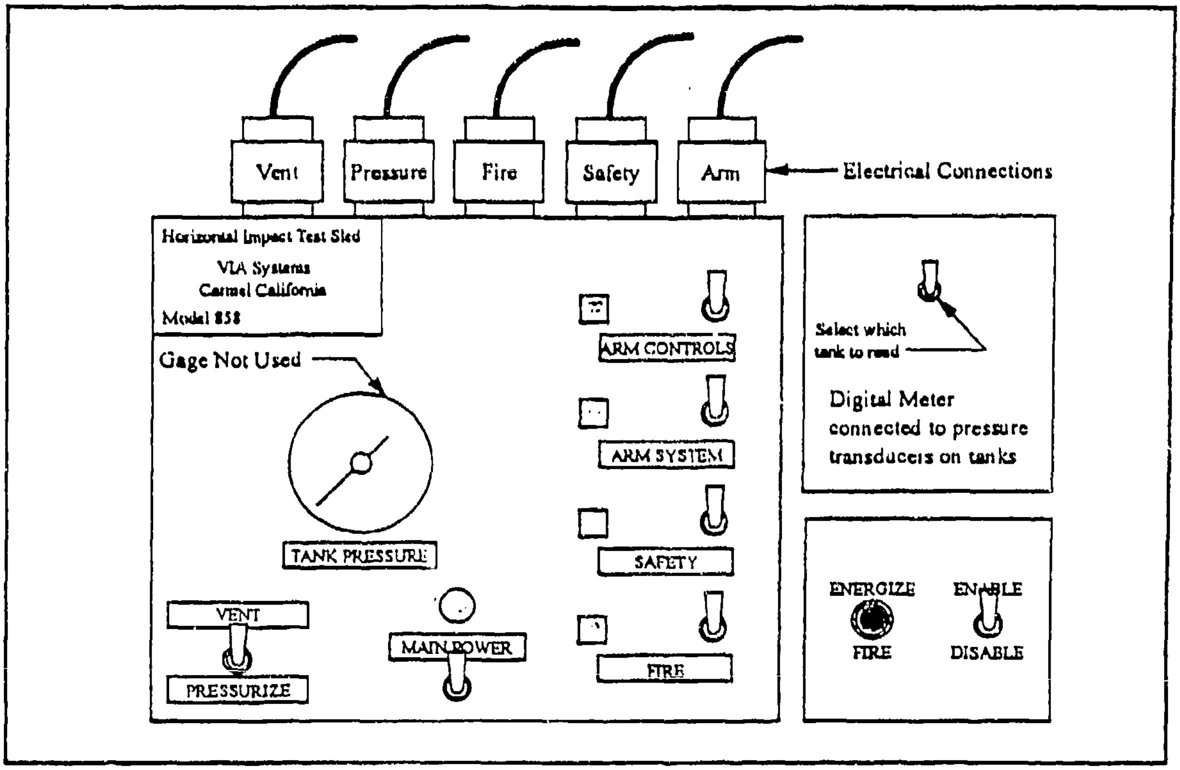


Figure 3.2.3
Propulsion System Control Panel

The switches on the right hand side of the panel are all connected and are turned on in sequence. The red light beside all four of the switches will turn on when they are in the on position.

The arm controls switch controls power to the other three switches. It is used to prevent someone accidentally pressing the fire button.

The arm system switch opens the first row of valves on the air tanks. These valves are the ones closest to the west end of the lab. These valves, shown in figure 3.2.1, must be open to fire the sled.

The next switch is for the safety pin. There is a pneumatically controlled pin at the East end of the track that holds the sled in place to prevent an accidental launching. The location of the safety pin is also shown in figure 3.2.1.

The next switch is the fire switch. It is no longer used to control the sled. Instead there is small box, the fire box, next to the control panel that contains the fire button. The fire button in the small box has an enable and disable switch that acts as an on/off control for the fire button. This new fire button is connected to a computer that triggers the data acquisition system, turns on the lights, and opens and then closes the firing valves.

The electrical lines that connect the switches with the propulsion system valves and tanks are plugged into the back of the control box. There is a connection for the safety, arm system, fire, vent and pressurize switches. There is a separate set of plugs for each of the two propulsion systems and only one can be used at a given time.

3.3) The Restraining System

The restraining system is responsible for decelerating the sled in a manner that represents the desired test conditions. The restraining system works by using the kinetic energy of the sled to deform a series of steel straps. The straps are plastically deformed when the sled probe forces them to be pulled through a set of rollers. It is this plastic or permanent deformation of the straps that absorbs the energy of the sled. A top view of the restraining system is shown in figure 3.3.1.

The straps are held in place on either side of where the probe contacts them. On one side is what is called the roller cage. The roller cage contains four rollers that deform the straps. A top view of the roller cage is shown in figure 3.3.2 and a front view is shown in figure 3.3.3. The other side is called the clamp cage. The clamp cage holds the straps fixed on one side.

The first roller in the roller cage is also called the idle roller. For a triangular pulse, the peak of the pulse is achieved when the end of the shortest strap of a given setup pulls past the center of the idle roller. At the top of the idle roller is what is referred to as the idle roller reinforcement arm. This removable steel arm serves to keep the idle roller in a vertical position when the straps push on it during a test.

The number three roller is also called the pressure roller. The pressure roller is connected to a hydraulic cylinder. When the cylinder is pressurized the pressure roller is pulled into the straps and thus deforms them. Once the pressure roller is drawn into the straps it will remain in that position throughout the test. There is a linear displacement transducer on the upper pressure roller. This transducer is used to make sure the pressure roller is pulled back the same distance for each test.

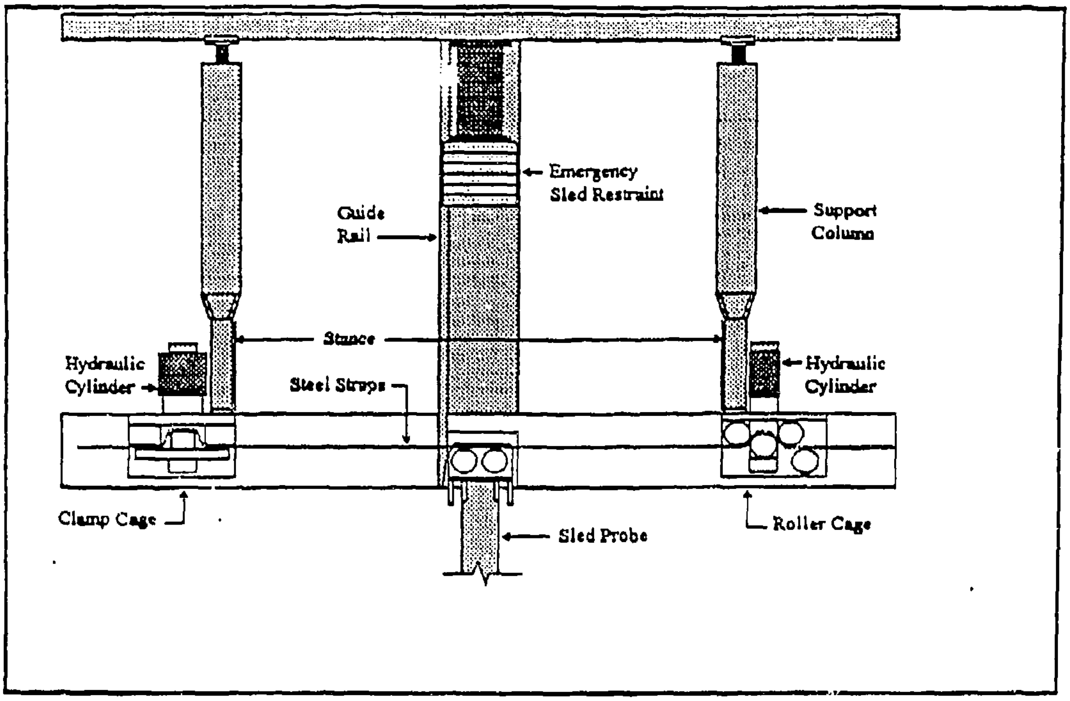


Figure 3.3.1
Restraining System

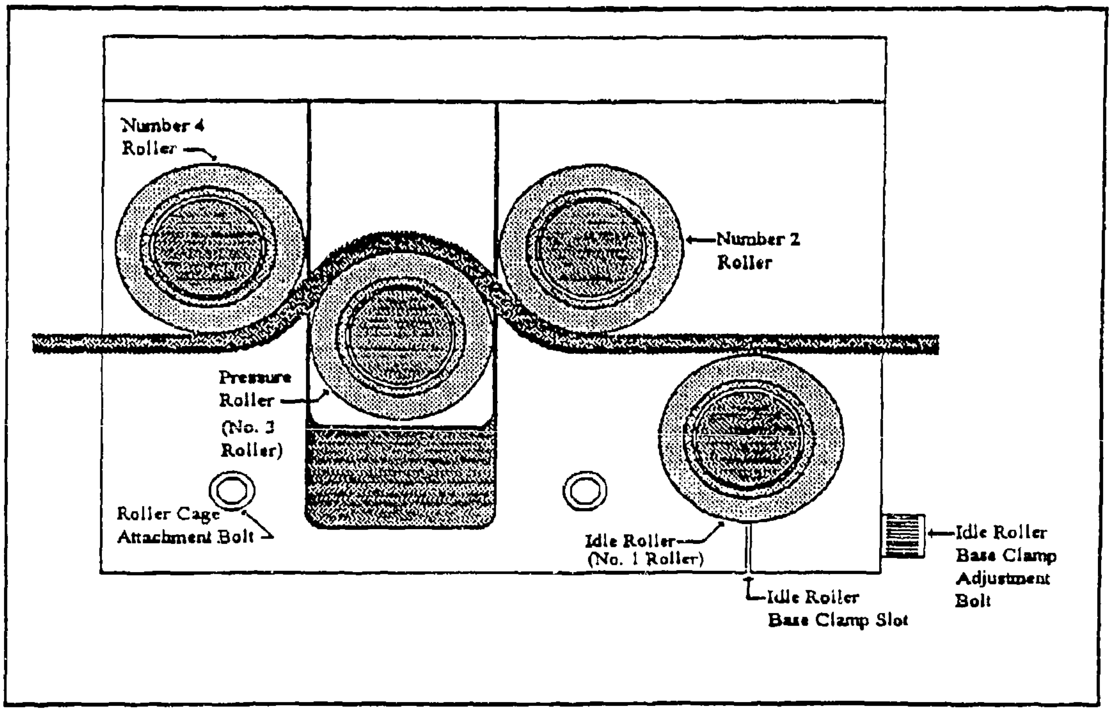


Figure 3.3.2
Top View of the Roller Cage

On the opposite side from the roller cage is what is called the clamp cage. The clamp cage holds the straps fixed so that their only motion will be to pull through the roller cage. The clamp cage has a hydraulic cylinder much like the roller cage. When this cylinder is pressurized the straps are clamped in place and not permitted to move.

The separation distance between the roller cage and the clamp cage is called the stance. The stance is variable and set as needed to achieve a desired test condition. The roller or clamp cage and the adjoining support column, shown in figure 3.3.1, move either in or out for stance adjustment.

Partially shown in figure 3.3.3 is the all thread rod. This rod runs between the roller cage and the clamp cage. When the probe contacts the straps, the tension forces in the straps will pull both the cages in towards each other. The threaded rod helps to hold the roller and clamp cages apart.

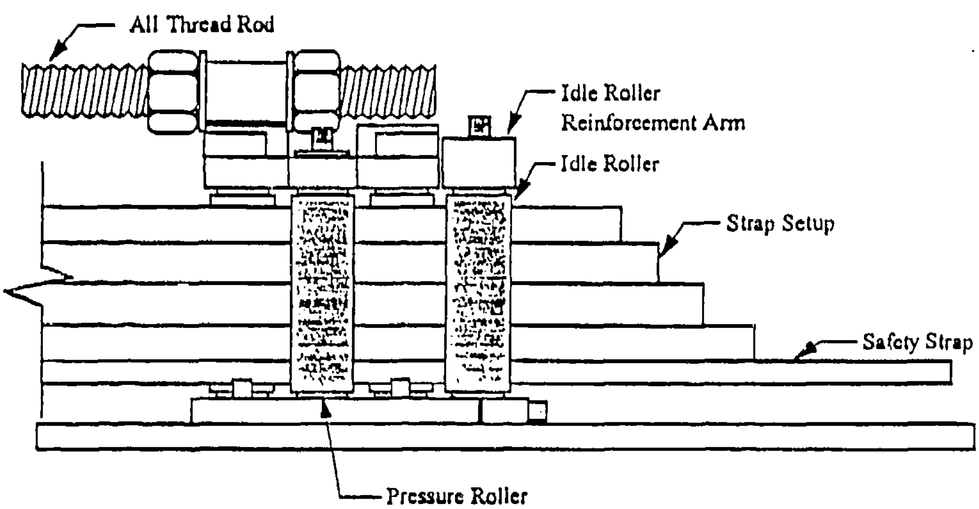


Figure 3.3.3
Front View of Roller Cage

3.4) The Data Acquisition System

The data system collects data from the tests and stores it so that post test analysis can be performed. The six main components of the data system are the DSP data acquisition system, the umbilical cable, the Impax software, the DSP Plot software, a 486/33 computer, and the interface box or "blue box" on the sled. A schematic of the data system is shown in figure 3.4.1.

The interface box is located at the rear of the sled. It is shown in figure 3.1.1. All transducers used on the sled must be connected into this box in order for their data to be

recorded during a test. There is one plug for each of the amplifiers in the DSP data acquisition system. This box is also known as the "blue box" because it is painted blue.

The Impax software is what controls the data acquisition system. All transducers that will be recorded during a test are entered into a test database. Once a transducer is entered into this database it can be zeroed and then used to record data during a test. Data that has been recorded by a transducer can also be processed by Impax. This processing includes filtering raw data or converting the data to an ASCII format.

The DSP Plot software is used to plot signals recorded by Impax. Since the data recorded by Impax is stored in its own special format, it can only be plotted using the DSP Plot package.

The DSP data acquisition system contains the signal amplifiers and the analog to digital converters. Each transducer that is used during a test is connected into its own amplifier. The data is sent from the transducer to the amplifier to the converter. The converter changes the data into a digital signal that then can be recorded and stored on the computer that contains the Impax and DSP Plot software. There are 64 data channels in the data acquisition system. Sixty of the channels are of the full bridge/signal condition type and the other four are of the op-amp type.

The 486/33 computer is located in the control room of the lab. This computer contains the Impax and DSP Plot software. It is also the storage location of the data collected for each test.

The umbilical cable is the interface between the interface box on the sled and the DSP data acquisition system. There is an individual cable for each amplifier in the data acquisition system. All of the individual cables are bundled together to form the umbilical cable. The connection of the umbilical cable with the sled can be seen in figure 3.1.1.

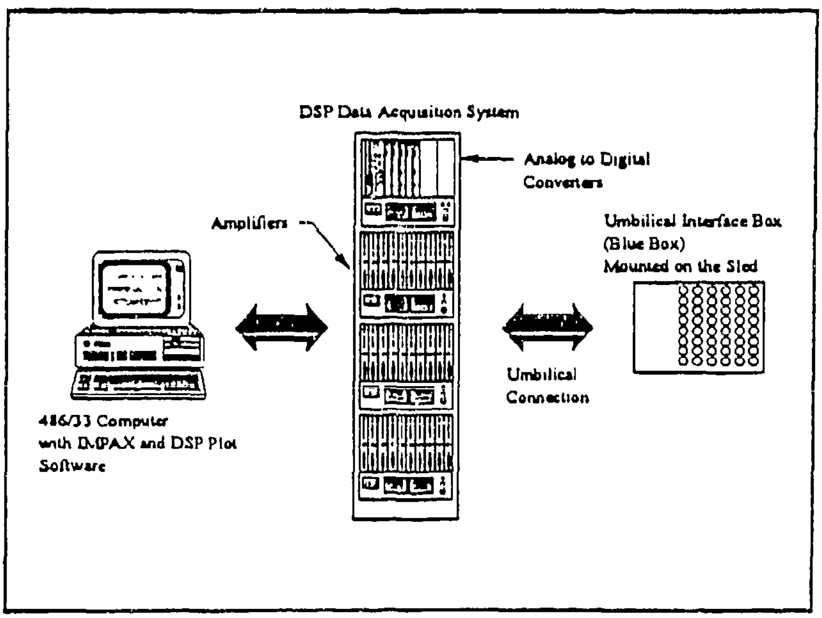


Figure 3.4.1
Data System

4.) Pulse Shaping

This section covers the steps necessary to produce a working pulse from a theoretical one. You will be taken through the procedures that were used to generate the pulses currently developed so that the procedures can be clearly demonstrated. A sample FAA pulse will be used as an example. The first five parts of this section will deal with the analytical procedures used and the remaining five will cover some of the empirical aspects involved such as the adjustment of pulse parameters and comparisons with past tests.

The procedures presented in this section are performed by the codes Triangle, Pulse, Speed, and Length. A copy of each of these codes is included in the appendix.

4.1) An Acceptable FAA Deceleration Pulse

Before going into how to construct a deceleration pulse it is necessary to know what constitutes an acceptable pulse. The document SAE AS8049 entitled "Performance Standards for Seats in Civil Rotorcraft and Transport Airplanes" describes the parameters that must be met for a pulse to be considered satisfactory by FAA standards. It also demonstrates how to show that a particular pulse complies with these standards.

There are five main requirements that must be met in order for a pulse to be considered successful. These are peak G level, rise time, velocity change during the rise time, total velocity change and the velocity of the sled at impact. The impact velocity, however is a function of the sled propulsion system so it will be dealt with separately in a later section. A typical deceleration pulse is shown in figure 4.1.1.

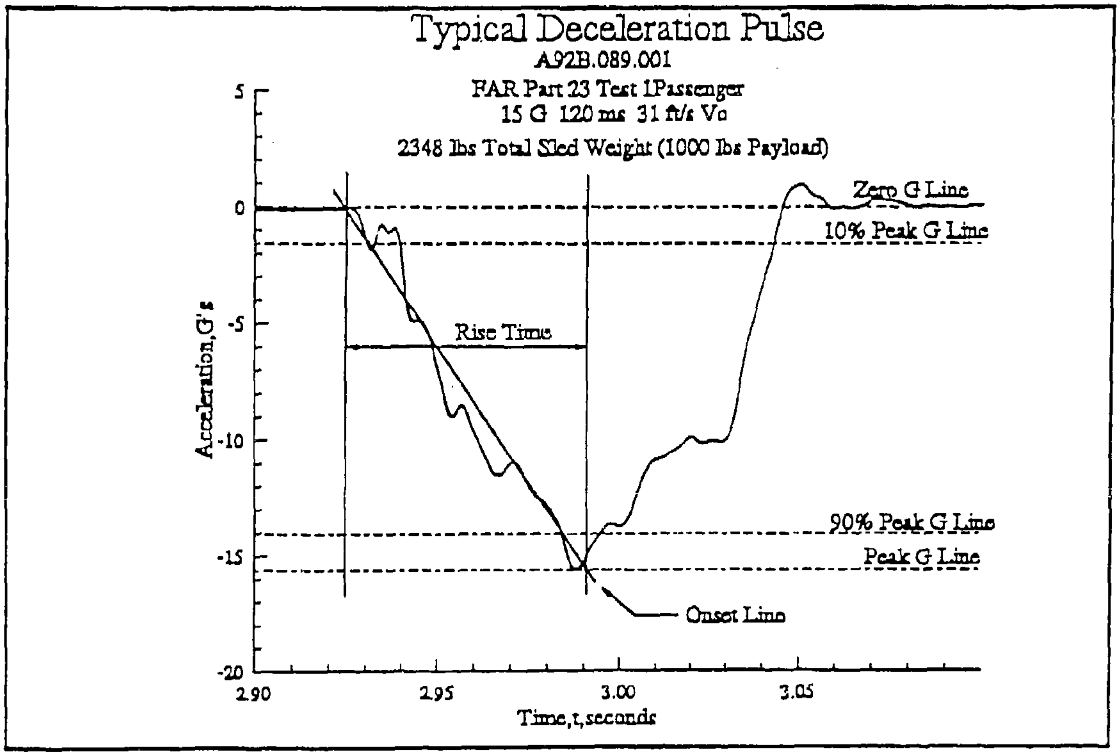


Figure 4.1.1
Typical Deceleration Pulse

Two methods are valid for determining if a pulse generated in a test is successful. The first is a simple comparison with the ideal pulse where the ideal pulse is superimposed upon the test pulse. If the test pulse is greater than or equal to the ideal pulse, it is considered acceptable. The second method is graphical and can be used to evaluate pulses that are not precisely isosceles triangles. This process begins by drawing a line through the zero G line on the sled acceleration plot. Second, a line is drawn through the maximum G line. The G level at the maximum G line represents the peak G level for the pulse. Lines are then constructed at 10% and 90% of the maximum G line. A line, called the onset line, which passes through the intersections of the sled acceleration curve and the 10% and 90% lines is drawn. This line should be extended to the zero and maximum G lines. The point where the onset line intersects the zero G line is called the time zero point of the pulse. The time interval between the time zero point and the intersection of the onset line with the maximum G line represents the rise time of the pulse. The rise time of the test pulse is acceptable if it is less than or equal to the rise time of the ideal pulse. The area under the sled acceleration versus time curve from the time zero point to a time equal to the theoretical rise time represents the velocity change during the rise time. The rise time velocity change should be greater than or equal to one half of the prescribed impact velocity. The total velocity change is the area under the sled acceleration versus time plot from the time zero point to a time equal to 2.3 times the theoretical rise time or the time when the sled acceleration returns to zero, whichever occurs first.

If these four parameters, peak G level, rise time, rise time velocity change, and total velocity change, are met and the impact velocity is greater than or equal to the prescribed value, the pulse is deemed to be acceptable. Now that the definition of an acceptable deceleration pulse is known we can proceed to develop a pulse to meet these parameters.

4.2) Integrating an Ideal Pulse

The first step in developing a pulse starts with the ideal pulse shape. This pulse will represent the loading necessary for a particular test. The pulse will generally be given in a G's versus time format, so the first step is to convert G's into ft/s^2 and to change the time scale to seconds. This will keep the units consistent as the pulse is integrated to get both velocity and displacement. The pulse is integrated to determine the displacement of the sled past the impact position, also called the stroke, as a function of time. This information will be necessary when we attempt to select straps and in determining the lengths of those straps.

The acceleration versus time equation of the ideal pulse must be determined. For the triangular pulse that we will examine, unit step functions will be used to model the pulse. The sample pulse is shown in figure 4.2.1. This pulse is for FAR part 23 tests for passenger seats. The pulse is defined to be an isosceles triangle with a peak of 15 G's, a rise time of 60 milliseconds and an impact velocity of 31 ft/s.

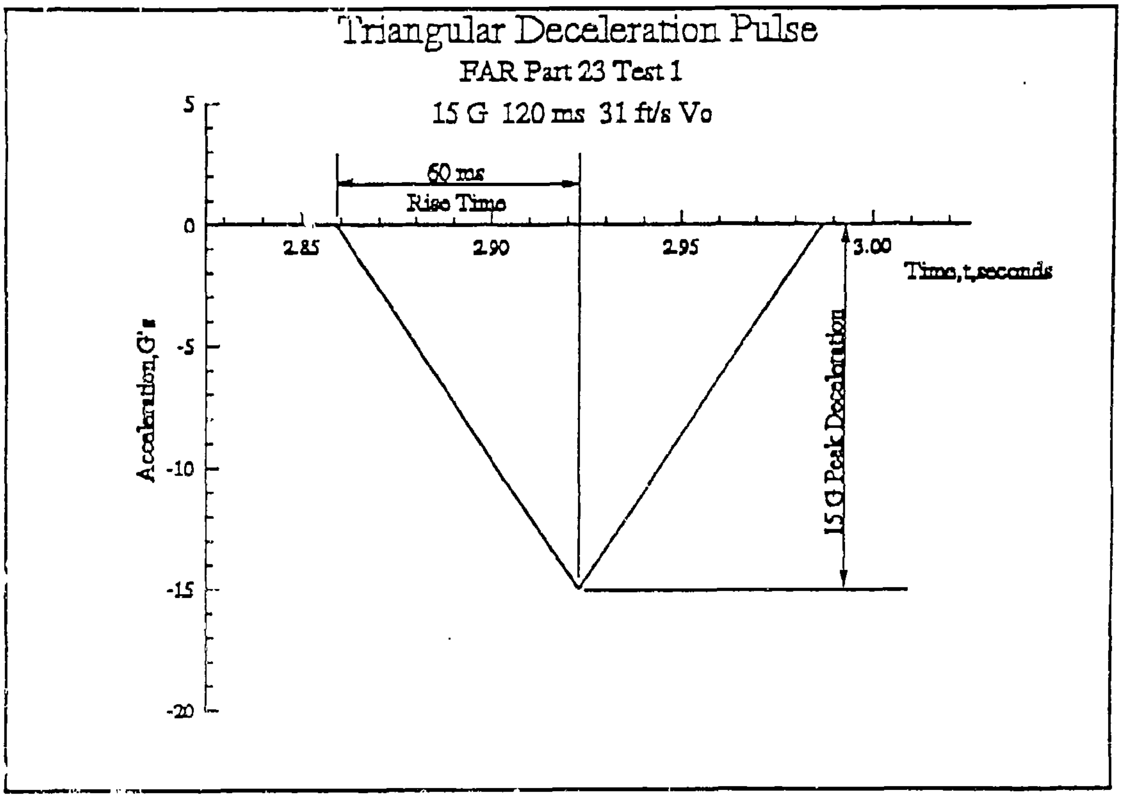


Figure 4.2.1
Ideal Triangular Pulse

Since the area under the curve represents the total velocity change or the velocity of the sled at impact, there exists a relationship between peak G level, a_0, the impact velocity, V_0, and twice the rise time or the pulse duration, τ. This relationship is;

$$V_o = \frac{1}{2} \cdot a_o \cdot \tau \quad \text{or upon rearranging} \quad a_o = 2 \cdot \frac{V_o}{\tau} \qquad (4.2.1.a,b)$$

It is important to note that the three prescribed values for the pulse, impact velocity, peak G level, and rise time, will not exactly satisfy the above relationship. For instance if we input the pulse duration of 120 milliseconds and an impact velocity of 31 ft/s into equation 4.2.1.b, the peak G level will be 16.0 instead of the prescribed 15. The pulse duration will calculate out to be 128.36 milliseconds if we input the peak G level and the prescribed impact velocity. It has been our practice to integrate the pulse using the proper G level and impact velocity. The pulse is then developed to meet the rise time requirement with the extra pulse duration time occurring after the peak of the pulse.

The equation for the pulse is;

$$a(t) = \left(2\frac{a_0}{\tau}\right)\cdot\left[-t\cdot u(t) + 2\cdot\left(t-\frac{\tau}{2}\right)\cdot u\left(t-\frac{\tau}{2}\right) - (t-\tau)\cdot u(t-\tau)\right] \qquad (4.2.2)$$

We will now insert the relationship for a_0 from above;

$$a(t) = \left(4\frac{V_0}{\tau^2}\right)\cdot\left[-t\cdot u(t) + 2\cdot\left(t-\frac{\tau}{2}\right)\cdot u\left(t-\frac{\tau}{2}\right) - (t-\tau)\cdot u(t-\tau)\right] \qquad (4.2.3)$$

This equation can now be integrated to get the equation for velocity as a function of time. The initial conditions will be;

$$V(0) = V_0 \quad \text{and} \quad V\left(\frac{\tau}{2}\right) = \frac{V_0}{2} \qquad (4.2.4)$$

So that the velocity equation will be;

$$V(t) = V_0 + \left(2\frac{V_0}{\tau^2}\right)\cdot\left[-t^2\cdot u(t) + 2\cdot\left(t-\frac{\tau}{2}\right)^2\cdot u\left(t-\frac{\tau}{2}\right) - (t-\tau)^2\cdot u(t-\tau)\right] \qquad (4.2.5)$$

Integrating again to obtain the displacement equation we get;

$$S(t) = V_0\cdot t + \left(\frac{2}{3}\frac{V_0}{\tau^2}\right)\cdot\left[-t^3\cdot u(t) + 2\cdot\left(t-\frac{\tau}{2}\right)^3\cdot u\left(t-\frac{\tau}{2}\right) - (t-\tau)^3\cdot u(t-\tau)\right] \qquad (4.2.6)$$

Now knowing the equation for the displacement of the sled the stroke at the peak of the pulse and the total stroke can be found by substituting $t = \tau/2$ and $t = \tau$. These values are;

$$S\left(\frac{\tau}{2}\right) = \frac{5}{12}\cdot V_0\cdot\tau \qquad (4.2.7) \qquad \text{and} \qquad S(\tau) = \frac{6}{12}\cdot V_0\cdot\tau \qquad (4.2.8)$$

For the 15 G pulse the stroke at the peak would be 19.9 inches and the total stroke 23.9 inches. The theoretical force versus displacement curve for the pulse can now be plotted. In figure 4.2.2 force per unit mass, or acceleration, is plotted versus displacement for the example pulse. The restraining system must develop an opposing force equal to the curve shown in figure 4.2.2. If the force per unit mass values are multiplied by the weight of the sled, the resisting force the restraining system must provide can be found.

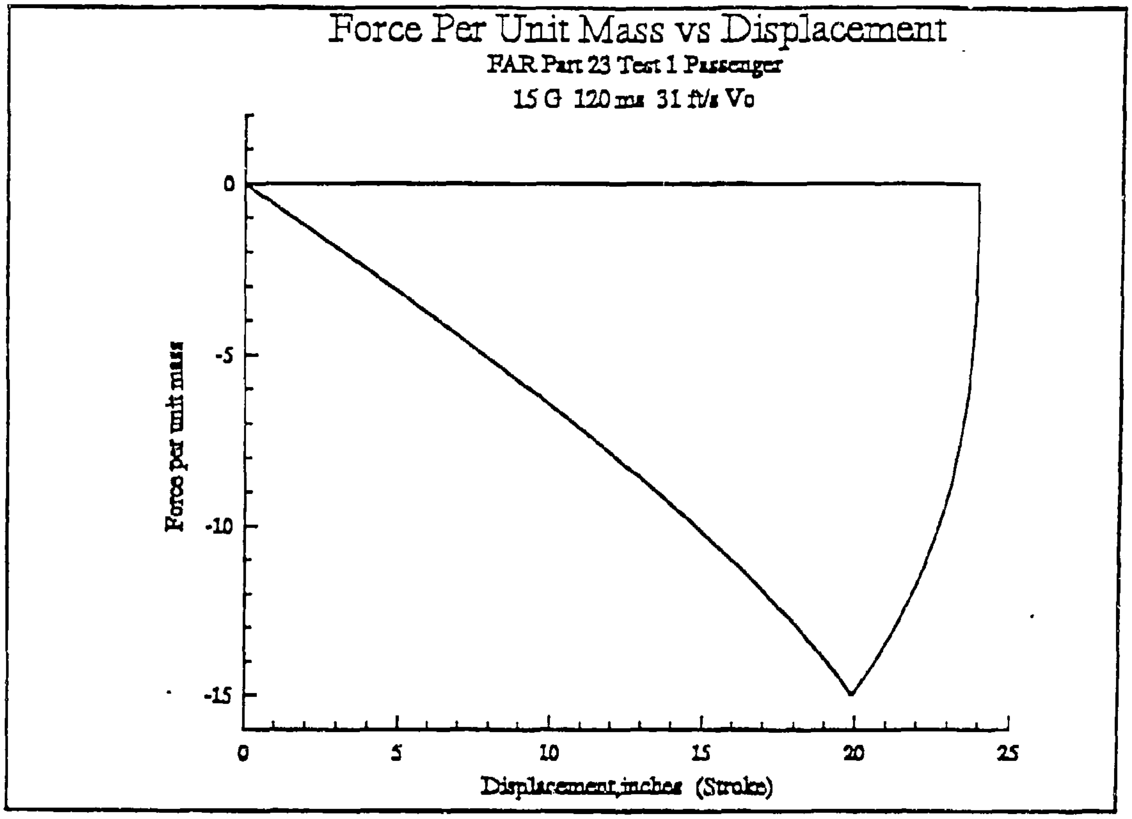


Figure 4.2.2
Theoretical Force vs. Displacement Curve
15 G 120 Millisecond Pulse 31 ft/s Impact Velocity

4.3) Selecting Straps Using Static Data

The straps in the restraining system must produce a force versus displacement profile opposite in magnitude to that for the ideal pulse. The static tests that were conducted in the summer of 1991 resulted in a force versus displacement curve for each of the straps used in the restraining system. These tests were conducted at a variety of stances ranging from 17.25 to 62.25 inches. With the aid of the static data a stance and combination of straps that will achieve a desired pulse can be determined.

A convenient way of selecting a strap setup is to look at the load necessary at the peak of the pulse. For our example 15 G pulse the stroke at the peak is 19.9 inches and the resisting force the straps must provide is 15 times the sled weight of 2348 pounds, or 35220 pounds. This can be seen in the plot of the strap force necessary versus stroke shown in figure 4.3.1.

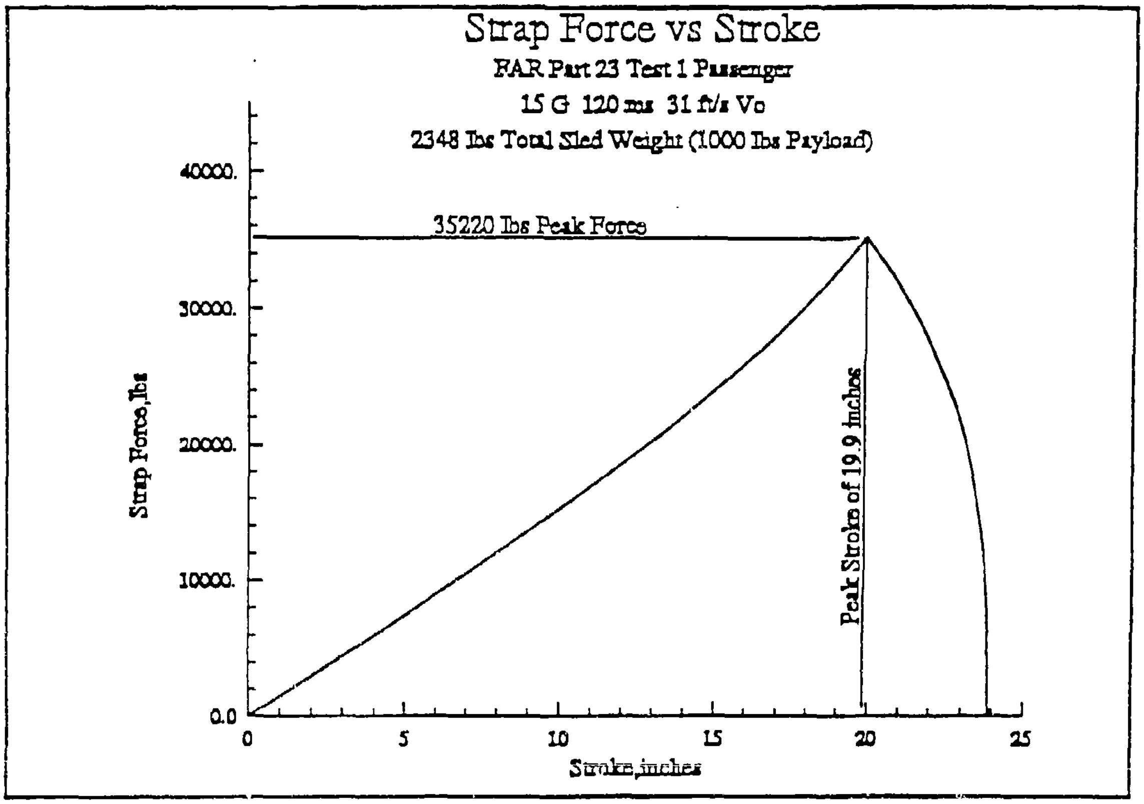


Figure 4.3.1
Strap Force vs. Stroke

If we search through the static data until a stance is found at which 35220 pounds can be provided at a stroke of 19.9 inches, it is then a matter of selecting a combination of straps that will best approximate the force versus displacement profile in figure 4.3.1.

When searching for a stance, it is advantageous to start with the widest one possible and move in from there. As stance increases the amount of strap that is pulled through the roller cage increases. Ideally all of the straps except the safety strap should be pulled completely through the roller cage. With a wide stance as opposed to a narrower

one, there is a greater chance of this happening. The maximum height for any combination of straps is seven inches. By calculating the force that seven inches of straps can provide at the peak stroke of a pulse, it can be determined whether the pulse can be achieved for a particular stance. For the example pulse the widest stance at which this pulse can be achieved is 52.25 inches. For seven inches of quarter inch thick straps at a 52.25 inch stance table 4.3.1 shows that the strap force at the peak stroke of the pulse is 48775 pounds while the necessary peak force is 35220 pounds.

Once a stance is found a combination of straps that provides the necessary resisting force can be selected. Since there are two thicknesses of straps available, 1/4 and 3/16 inches, it must be determined if the pulse can be developed with the 3/16 inch thick straps or if the 1/4 inch thick straps must be used. The 15 G pulse we have been looking at requires the use of the 1/4 inch thick straps since the 3/16 inch straps will only provide 24900 pounds at the peak stroke of the pulse. Figure 4.3.2 shows curve fits of the static data for 1/4 inch thick straps at a stance of 52.25 inches. From past experience the load

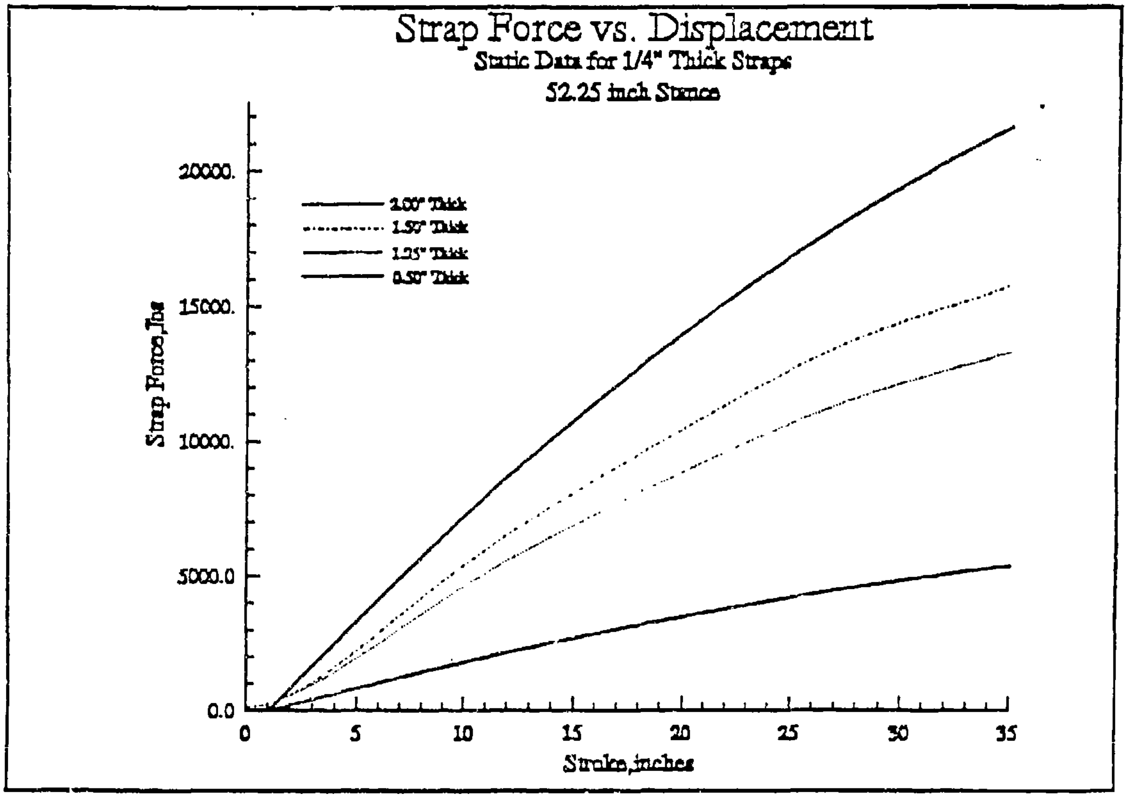


Figure 4.3.2
Static Data for 1/4 inch Straps at a 52.52 inch Stance

the straps produce at the peak of the pulse must be slightly higher than the theoretical 35220 pounds. The amount of this overshoot has averaged 6500 pounds. This extra force must be taken into account when selecting a strap setup. Taking this into account the peak force we will be aiming for, including the 6500 pounds, will now be 41720 pounds.

Also important when selecting a combination of straps is the back side of the pulse. The pulse can be thought of as having two parts, or sides. The front side is the part

from the start of the pulse up to the peak. The back side is the part from the peak to the point when the pulse returns back to a zero G level. As was discussed in section 3.3 the peak of the pulse will occur when the shortest of several straps is pulled past the idle roller. After a strap passes the center of the idle roller the resisting force the strap provides decreases to zero. The resisting force reaches zero when the strap is pulled completely through the roller cage. The lengths of the straps other than the shortest one serve to determine the shape of the back side of the pulse. It is advantageous to have the largest number of straps possible in order to have the maximum possible control over the back side of the pulse.

Keeping in mind the back side of the pulse, and the overshoot of the peak force a strap combination can now be selected that will provide an acceptable first attempt at the 15 G pulse. Table 4.3.1 lists the strap forces for the 1/4 inch straps at the peak stroke. A strap setup consisting of two 1.50" x ¼" straps, two 1.25" x ¼" straps and two 0.50" x ¼" straps will provide a force of 45456 pounds at the peak of the pulse. It is important to note here that the 60 millisecond rise time is a maximum value. It is therefore advantageous to develop a pulse that has a slightly shorter rise time in order to make sure the rise time requirement is met. This also leads to a strap combination that is slightly stiffer that what is theoretically required.

Strap	Load, pounds
2.00" x ¼"	13935.63
1.50" x ¼"	10416.04
1.25" x ¼"	8827.80
0.50" x ¼"	3483.91

Table 4.3.1
Strap Forces from Static Data for a 52.25" Stance

The strap combination from the static data can now be plotted against the theoretical force versus displacement curve shown in figure 4.3.1. The loads of the six individual straps are added together to determine their combined effect. The loading the straps will provide, based on static data is shown along with the theoretical force versus displacement curve, in figure 4.3.3. From figure 4.3.3 the overshoot at the peak stroke of the pulse can be seen.

The data collected from all of the static tests was curve fitted. This data is contained in the subroutine Straps that is used by the code Pulse. As was previously mentioned both of these codes are included in the appendix.

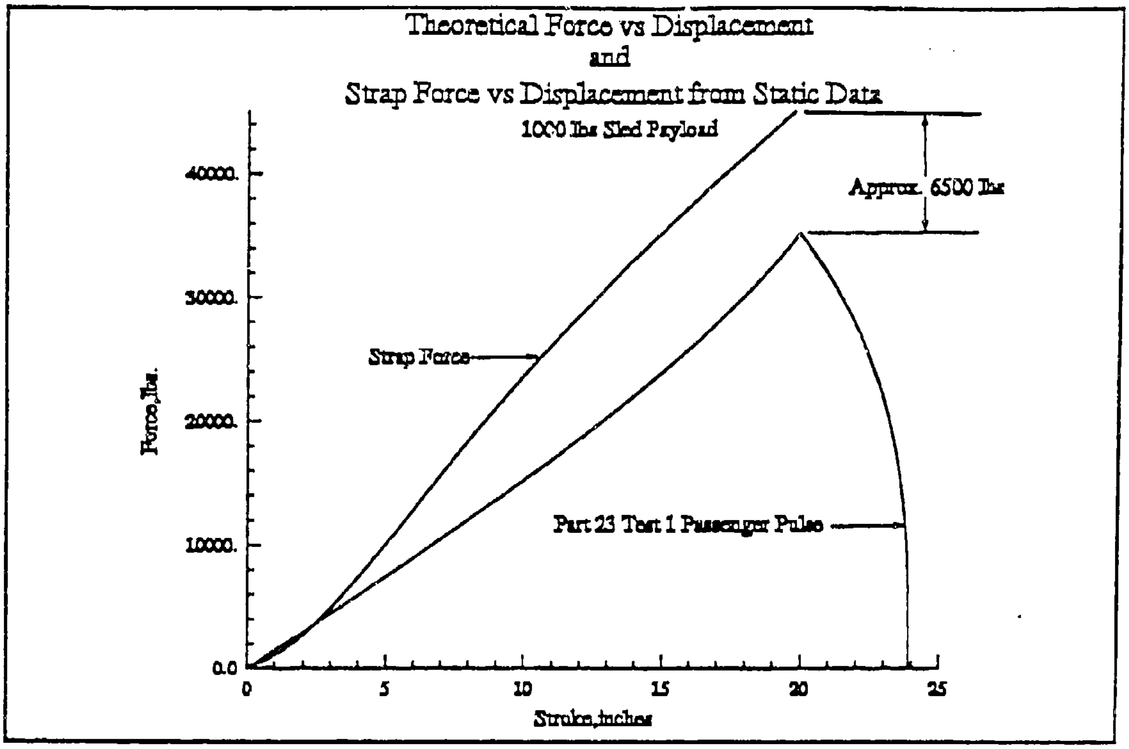


Figure 4.3.3
Strap and Theoretical Force vs. Displacement

4.4) Calculation of Strap Lengths

Once the number of straps needed is determined, the length of those straps must be also be determined. The length that is of importance when creating a pulse is the strap length up to the midpoint of the idle roller at the peak stroke of the pulse. For a triangular pulse when the shortest strap of a given setup passes the point of last contact with the idle roller the peak of the pulse is defined. We want the shortest strap from the example 15 G pulse to be at this point of last contact with the idle roller when the sled stroke is equal to the theoretical peak stroke of 19.9 inches. This will, in theory, put the peak of the pulse at 60 milliseconds into the pulse, the specified rise time.

To understand how to calculate strap lengths an understanding of the geometry of a strap being pulled through the restraining system is needed. We will examine the method currently used to calculate strap lengths using one of the straps from the 15 G pulse from section 4.2 as an example. The current method of strap length calculation is based solely on geometry. Any permanent deformation of the straps is not taken into account. This method is not exact but will provide an acceptable first approximation to the necessary strap length.

The strap length calculation will be done in three parts. The first part will be to calculate the strap length from the center of roller number four to where the strap last

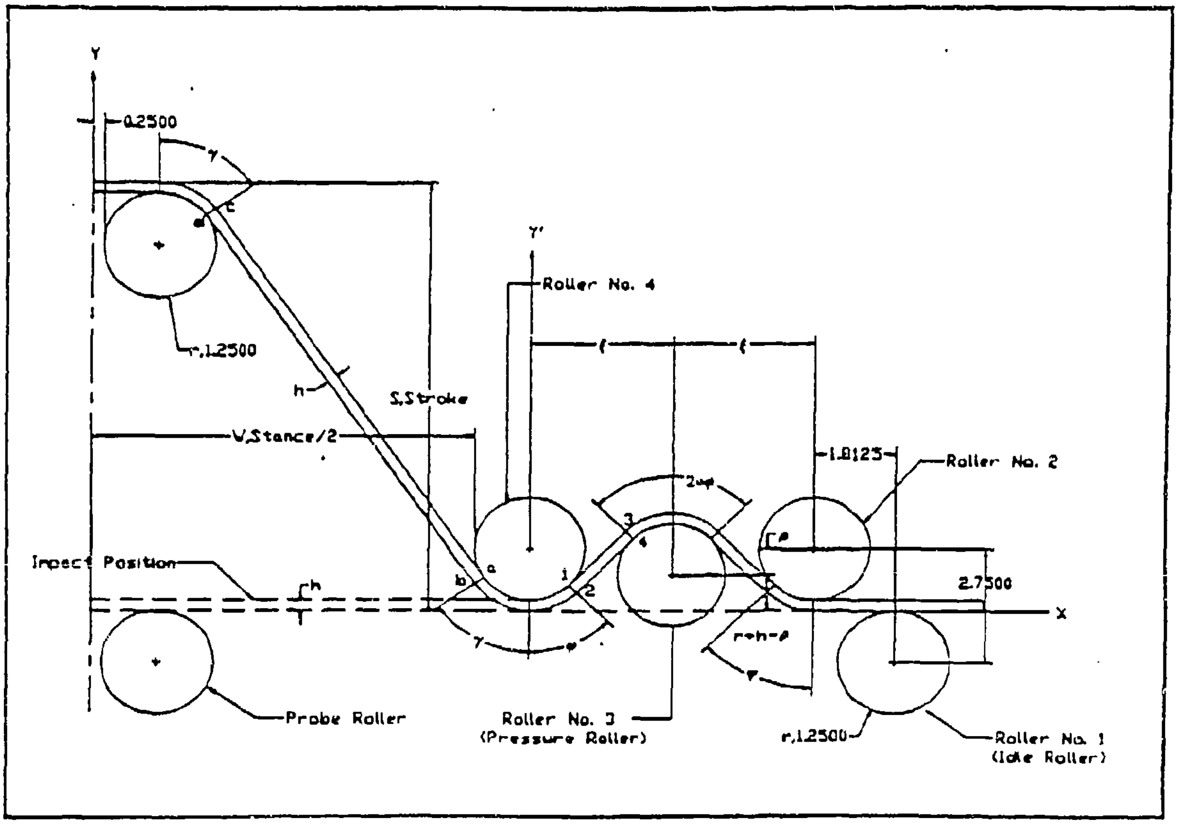


Figure 4.4.1
Strap from Probe Center through Roller Cage

contacts the idle roller. The second part will be from the center of roller number four upto the center of the sled probe. The third part will be from the center of the sled probe through the clamp cage.

Figure 4.4.1 shows a strap from the center of the sled probe through the roller cage. Figure 4.4.2 shows the strap from the center of the sled probe up to the start of the clamp cage.

There are several dimensions that must be identified prior to calculating the strap length. The horizontal spacing between rollers 2, 3, and 4 is denoted by the variable ξ. The value of ξ is 3.25 inches. The vertical separation between the centers of rollers 2 and 4 and roller 3 is denoted by ρ. The value of ρ is 0.625 inches. The pressure roller has moved 2.25 inches from its starting position when it reaches this value of ρ. The radius of the rollers is called r in the equations below. The roller radius is 1.25 inches. The stroke of the sled is denoted by s and half of the magnitude of the stance by w. There are two contact angles. These angles are used to determine the amount of strap that is in contact with the rollers. These angles are denoted by γ and φ. The strap thickness is denoted by the variable h.

The first step is to determine the strap length from the center of roller 4 up to the center of the idle roller. There are seven strap segments that must be calculated within this length. Four of them, the lengths in contact with the rollers, are the same. The two lengths of strap between rollers 2 and 3 and rollers 3 and 4, that are not in contact with the rollers, are also the same. The remaining length is the one from the center of the idle roller to the center of the number two roller, which is a fixed distance.

To determine the contact angle, φ, we must first calculate the X and Y' coordinates of the points numbered 1 through 4. The coordinates are;

$$x_1 = r\cdot\sin(\varphi) \qquad y'_1 = r + h - r\cdot\cos(\varphi) \qquad (4.4.1.a,b)$$
$$x_2 = (r+h)\cdot\sin(\varphi) \qquad y'_2 = (r+h) - (r+h)\cdot\cos(\varphi) \qquad (4.4.2.a,b)$$
$$x_3 = \xi - (r+h)\cdot\sin(\varphi) \qquad y'_3 = r + h - \rho + (r+h)\cdot\cos(\varphi) \qquad (4.4.3.a,b)$$
$$x_4 = \xi - r\cdot\sin(\varphi) \qquad y'_4 = r + h - \rho + r\cdot\cos(\varphi) \qquad (4.4.4.a,b)$$

Now using points 2 and 4 the tangent of the angle φ can be calculated.

$$\tan(\varphi) = \frac{y'_4 - y'_2}{x_4 - x_2} = \frac{r + h - \rho + r\cdot\cos(\varphi) - (r+h) + (r+h)\cdot\cos(\varphi)}{\xi - r\cdot\sin(\varphi) - (r+h)\cdot\sin(\varphi)} \qquad (4.4.5)$$

This can be further simplified and the tangent of the contact angle φ can be replaced by sine divided by cosine.

$$\tan(\varphi) = \frac{\sin(\varphi)}{\cos(\varphi)} = \frac{(2\cdot r + h)\cdot\cos(\varphi) - \rho}{\xi - (2\cdot r + h)\cdot\sin(\varphi)} \qquad (4.4.6)$$

If the numerator of 4.4.6 is multiplied by the cosine of φ and the denominator by the sine of the angle, and the entire equation is squared, a quadratic equation for the sine of φ can be developed. This equation can then be solved to determine the contact angle.

$$(\xi^2 + \rho^2)\cdot\sin^2(\varphi) - 2\cdot\xi\cdot(2\cdot r + h)\cdot\sin(\varphi) + \left[(2\cdot r + h)^2 - \rho^2\right] = 0 \qquad (4.4.7)$$

There will be two values of the contact angle that result from this equation. If the Y' coordinate of the pressure roller is smaller than the Y' coordinate of either rollers 2 or

4, the angle is the smaller of the two. The contact angle is the larger angle if the Y' coordinate of the pressure roller is greater than that of rollers 2 or 4.

Once the angle φ is determined the lengths of all of the segments inside the roller cage can be determined. When the strap length is calculated, it is calculated at the center of the strap. This means the radial distance from the center of a roller to the midpoint of the strap is needed. This radial distance is;

$$r_{mid} = r + \frac{h}{2} \qquad (4.4.8)$$

The arc length of the four segments that are in contact with the rollers is;

$$l_1 = 4 \cdot \varphi \cdot r_{mid} \qquad (4.4.9)$$

To calculate the lengths of the strap not in contact with the rollers, the distance from the center of rollers three and four to the center of the strap, at the point of last contact with the rollers, must be calculated. These lengths are;

$$x_{mid_{1-2}} = r_{mid} \cdot \sin(\varphi) \qquad y'_{mid_{1-2}} = r_{mid} + h - r_{mid} \cdot \cos(\varphi) \qquad (4.4.10.a,b)$$

$$x_{mid_{3-4}} = \xi - r_{mid} \cdot \sin(\varphi) \qquad y'_{mid_{3-4}} = r_{mid} + h - \rho + r_{mid} \cdot \cos(\varphi) \qquad (4.4.11.a,b)$$

The length of the segments that are not in contact with the rollers can then be found from these two points.

$$l_2 = 2 \cdot \sqrt{\left(y'_{mid_{3-4}} - y'_{mid_{1-2}}\right)^2 + \left(x_{mid_{3-4}} - x_{mid_{1-2}}\right)^2} \qquad (4.4.12)$$

The length of strap between the center of the idle roller and the number 2 roller is;

$$l_3 = 1.8125 \qquad (4.4.13)$$

The total length of strap from the center of the idle roller up to the center of the number four roller is;

$$L_{Total\,1-3} = l_1 + l_2 + l_3 \qquad (4.4.14)$$

The next segment to examine is from the midpoint of roller number four up to the center of the sled probe. To do this there is another contact angle, γ, that must be determined. The same approach will be taken to determine the angle γ as was used to find the angle φ. For this segment the points a through d will be used. The X and Y coordinates of these points are;

$$x_a = w + r - r \cdot \sin(\gamma) \qquad y_a = r + h - r \cdot \cos(\gamma) \qquad (4.4.15.a,b)$$

$$x_b = w + r - (r+h) \cdot \sin(\gamma) \qquad y_b = r + h - (r+h) \cdot \cos(\gamma) \qquad (4.4.16.a,b)$$

$$x_c = \frac{1}{4} + r + (r+h) \cdot \sin(\gamma) \qquad y_c = s - r + (r+h) \cdot \cos(\gamma) \qquad (4.4.17.a,b)$$

$$x_d = \frac{1}{4} + r + r \cdot \sin(\gamma) \qquad y_d = s - r + r \cdot \cos(\gamma) \qquad (4.4.18.a,b)$$

This time the points b and d will be used to calculate the tangent of the contact angle γ.

$$\tan(\gamma) = \frac{\sin(\gamma)}{\cos(\gamma)} = \frac{y_d - y_b}{x_b - x_d} = \frac{s - r + r \cdot \cos(\gamma) - (r+h) + (r+h) \cdot \cos(\gamma)}{w + r - (r+h) \cdot \sin(\gamma) - \frac{1}{4} - r - r \cdot \sin(\gamma)} \qquad (4.4.19)$$

This equation reduces to a quadratic equation for the sine of the contact angle γ. This equation is;

$$\left[\left(w-\frac{1}{4}\right)^2+(s-(2\cdot r+h))^2\right]\cdot\sin^2(\gamma)$$

$$-\left[2\cdot(2\cdot r+h)\cdot\left(w-\frac{1}{4}\right)\right]\cdot\sin(\gamma)+\left[(2\cdot r+h)^2-(s-(2\cdot r+h))^2\right]=0 \qquad (4.4.20)$$

Once again there will be two results returned from equation 4.4.20. If the stroke of the sled is less than the distance 2r+h the contact angle will be the smaller of the two. The angle will be the larger of the two is the stroke is greater than the 2r+h distance.

The two segments that represent the length of strap in contact with the rollers can be determined once γ is determined. The radial distance for the arc length calculation is the distance from the center of a roller to the midpoint of a strap as defined in equation 4.4.8. The total of these two lengths are;

$$l_4 = 2\cdot\gamma\cdot r_{mid} \qquad (4.4.21)$$

The coordinates of the points midway between points a and b and midway between points c and d are necessary to determine the length of strap that is not in contact with the rollers. The X and Y coordinates of these points are;

$$ab_{mid_x} = w + r - r_{mid}\cdot\sin(\gamma) \qquad ab_{mid_y} = r + h - r_{mid}\cdot\sin(\gamma) \qquad (4.4.22.a,b)$$

$$cd_{mid_x} = \frac{1}{4} + r + r_{mid}\cdot\sin(\gamma) \qquad cd_{mid_y} = s - r + r_{mid}\cdot\cos(\gamma) \qquad (4.4.23.a,b)$$

The length of the segment can now be determined from these two points.

$$l_5 = \sqrt{\left(ab_{mid_y} - cd_{mid_y}\right)^2 + \left(ab_{mid_x} - ab_{mid_x}\right)^2} \qquad (4.4.24.a,b)$$

The third length in this part of the strap is from the center line of the probe to the center of the probe roller. This distance is;

$$l_6 = \frac{1}{4} + r \qquad (4.4.25)$$

The total length of strap from the center of roller number 4 up to the center line of the sled probe is then;

$$L_{Total_{4-6}} = l_4 + l_5 + l_6 \qquad (4.4.26)$$

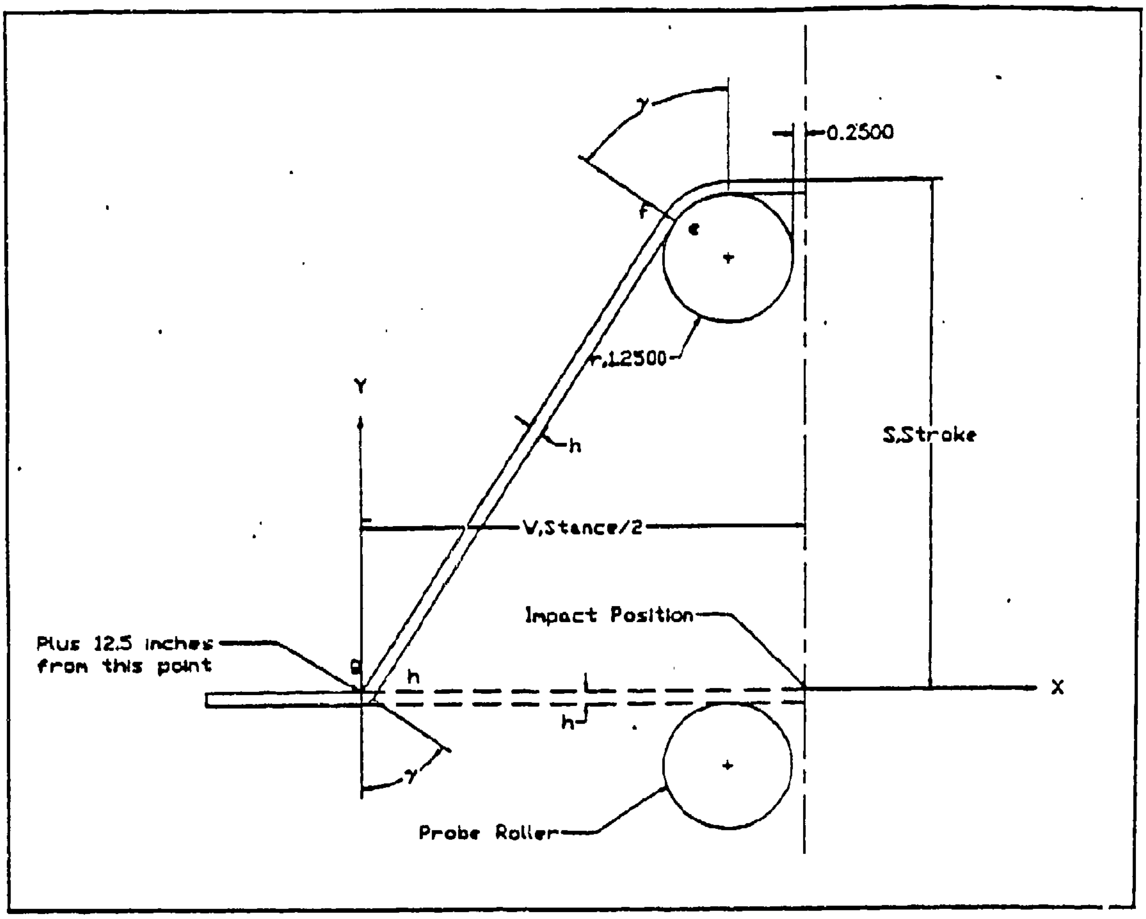


Figure 4.4.2
Strap From Center of Sled Probe through Clamp Cage

The final lengths of strap that need to be determined are from the center of the sled probe through the clamp cage. The contact angle between the strap and the probe roller on this side is assumed to be the same angle γ as on the roller cage side.

The first segment is from the probe center line up to the center of the probe roller. This distance is the same as equation 4.4.25.

$$l_7 = \frac{1}{4} + r \qquad (4.4.27)$$

The next segment is that in contact with the probe roller. This length is again the length of the arc of angle γ.

$$l_8 = r_{mid} \cdot \gamma \qquad (4.4.28)$$

The arc at the clamp cage side has the same angle γ but the radial distance is only h/2.

$$l_9 = \frac{h}{2} \cdot \gamma \qquad (4.4.29)$$

To determine the length between the probe roller and the clamp cage, the coordinates of the points at the center of the strap are necessary. These are the points midway between points e and f and between points g and h.

$$ef_{mid_x} = w - \frac{1}{4} - r - \left(r + \frac{h}{2}\right)\cdot\sin(\gamma) \quad ef_{mid_y} = s - r - h + \left(r + \frac{h}{2}\right)\cdot\cos(\gamma) \quad (4.4.30.a,b)$$

$$gh_{mid_x} = \frac{h}{2}\cdot\sin(\gamma) \qquad gh_{mid_y} = h - \frac{h}{2}\cdot\cos(\gamma) \qquad (4.4.31.a,b)$$

The length of this segment is then found from the coordinates of these two points.

$$l_{10} = \sqrt{\left(ef_{mid_y} - gh_{mid_y}\right)^2 + \left(ef_{mid_x} - gh_{mid_x}\right)^2} \qquad (4.4.32)$$

The remaining length is the length of strap that runs through the clamp cage. This length is always the same, twelve and a half inches. This makes the total length of strap on the clamp cage side;

$$L_{Total_{7-10}} = l_7 + l_8 + l_9 + l_{10} + 12\frac{1}{2}" \qquad (4.4.33)$$

The length of strap necessary for the given peak stroke is then the total of all of the individual strap lengths that have just been calculated. This total length is;

$$\text{Strap Length} = L_{Total_{1-3}} + L_{Total_{4-6}} + L_{Total_{7-10}} \qquad (4.4.34)$$

For the 15 G 120 millisecond pulse where the stance is 52.25 inches, we can calculate the length of the shortest strap of the setup so that the peak of the pulse occurs at a stroke of 19.9 inches. If the stance and stroke values are plugged into the above equations the length of the shortest strap is calculated to be 89.9 inches. The angle φ is 45.3 degrees and the angle γ is 38.6 degrees.

The lengths of the other straps in the setup must also be determined. To determine the length of the longest strap we could put the maximum stroke of the pulse into the above set of equations. This method, however, has not worked in practice. The above equations tend to suggest strap lengths that are longer than the lengths that are actually used. The spacing between succeeding straps is normally between one half an inch and one inch. These distances are based solely on the knowledge gained from past tests. For 15 G pulses similar to the example 15 G pulse that we are considering the spacing between straps has been one half inch between each strap.

From the experience gained from past tests there are several procedures that have arisen to help achieve the best possible pulse shape in the fewest number of attempts.

One important thing to keep in mind is that the prediction for strap lengths does not take into account the permanent deformation that occurs during an impact. Also the total stroke of the sled is always shorter than the total stroke predicted. The lengths of all the straps will have to be three to six inches less than that predicted by the above equations to take this into account. For the example 15 G pulse we will shorten the length of the shortest or first strap by 4.9 inches to 85 inches.

An important aspect of the pulse is that it have the correct shape. For the FAA pulses the shapes are all isosceles triangles. It is herefore advantageous to have a sharp well-defined peak as opposed to a rounded one. If there are two different widths of straps being used for the pulse, it is best to have the widest one also be the shortest one. For instance, if there is a 2.00"x1/4" strap and a 1.25"x1/4" strap, it is best to pull the 2.00"x1/4" strap past the idle roller first. This would produce the sharpest drop off in the load carrying capacity of the strap combination, thus producing the sharpest and most noticeable peak.

Another thing to keep in mind is the safety strap. This is the longest strap of the setup. The purpose of the safety strap is to restrain the sled in the event of something unforeseen happening. If the straps pull farther than expected, the safety strap would have to restrain the sled. The safety strap, which is placed at the bottom of the setup, should be an uncut twenty foot long strap.

For the 15 G pulse we can now determine the strap lengths for all of the straps being used. We will want to pull one of the widest straps first to achieve the sharpest peak, therefore one of the 1.50"x1/4" straps will be the shortest strap at 85 inches. The entire strap setup including lengths is shown in table 4.4.1.

Strap Number (Shortest Strap is #1)	Strap Size (Width x Thickness)	Strap Length (inches)
1	1.50" x ¼"	85
2	1.50" x ¼"	85½
3	1.25" x ¼"	86
4	1.25" x ¼"	86½
5	0.50" x ¼"	87
6	0.50" x ¼"	∞, Safety Strap

Table 4.4.1
Strap Lengths for 15 G 120 ms Pulse

The computer program called "Length" listed in the appendix will calculate a strap length based upon the theory presented in this section. The user must select a stance, a strap thickness, and enter a value for the stroke. The code will return a strap length in inches. Any reductions in the theoretical strap lengths must be made by the user.

4.5) Calculation of Propulsion System Parameters

The propulsion system must provide the sled with the necessary velocity at impact. It is desirable to have the sled coasting, or state of zero acceleration, at impact. There are two variables that must be determined prior to a test in order for the sled to attain the proper velocity. These parameters are system pressure and valve delay time. The system pressure is the amount of gage pressure in pounds per square inch in the tanks of the propulsion system. The delay time is the amount of time that the control valves, which allow air from the tanks to reach the piston, are open.

A free body diagram for the sled and piston system is shown in figure 4.5.1. The forces acting on it are the pressure force due to the air coming out of the air tanks, the friction force between the sled shoes and the tracks and the friction force between the piston and the pipe, and a fictitious force to represent the pressure losses in the system. These pressure losses come from gaps in the joints of the pipe that the piston travels in, and from gaps at the location where the sled tow cables enter the pipe.

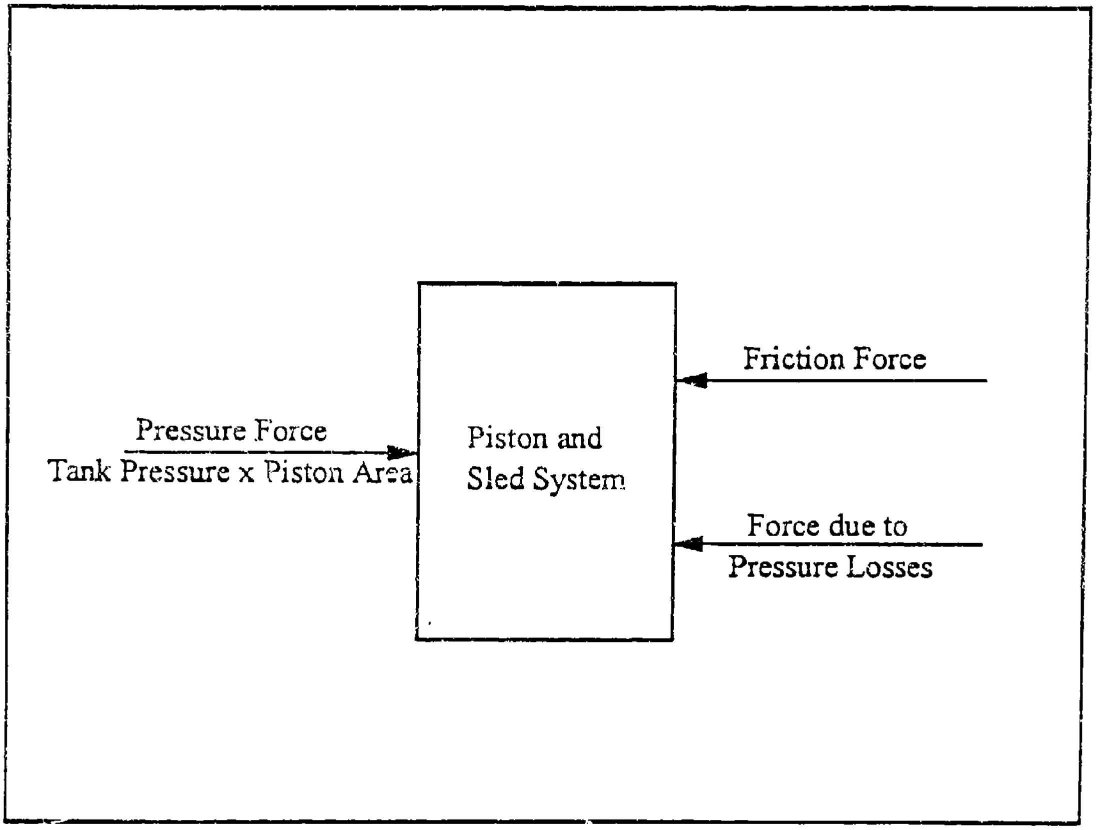


Figure 4.5.1
Free Body Diagram of Propulsion System

The interval during which the sled is in motion can be broken into three phases. The first is from the time the fire button is pressed, opening the control valves on the tanks, until the valves close This is time is called the delay time The second interval is from the time the valves close until the sled impacts the straps The third being from

impact to the time the sled stops. For the purposes of determining an impact velocity the first two intervals are most important.

Considering first the time interval during which the control valves on the tanks are open, an expression for the sled acceleration can be determined. This expression will be integrated to determine velocity and displacement. A diagram of the system during this first time interval is shown in figure 4.5.2. The initial pressure in the tanks is denoted by the variable P_O. This pressure value is the gage pressure value read from the pressure transducer on one of the tanks.

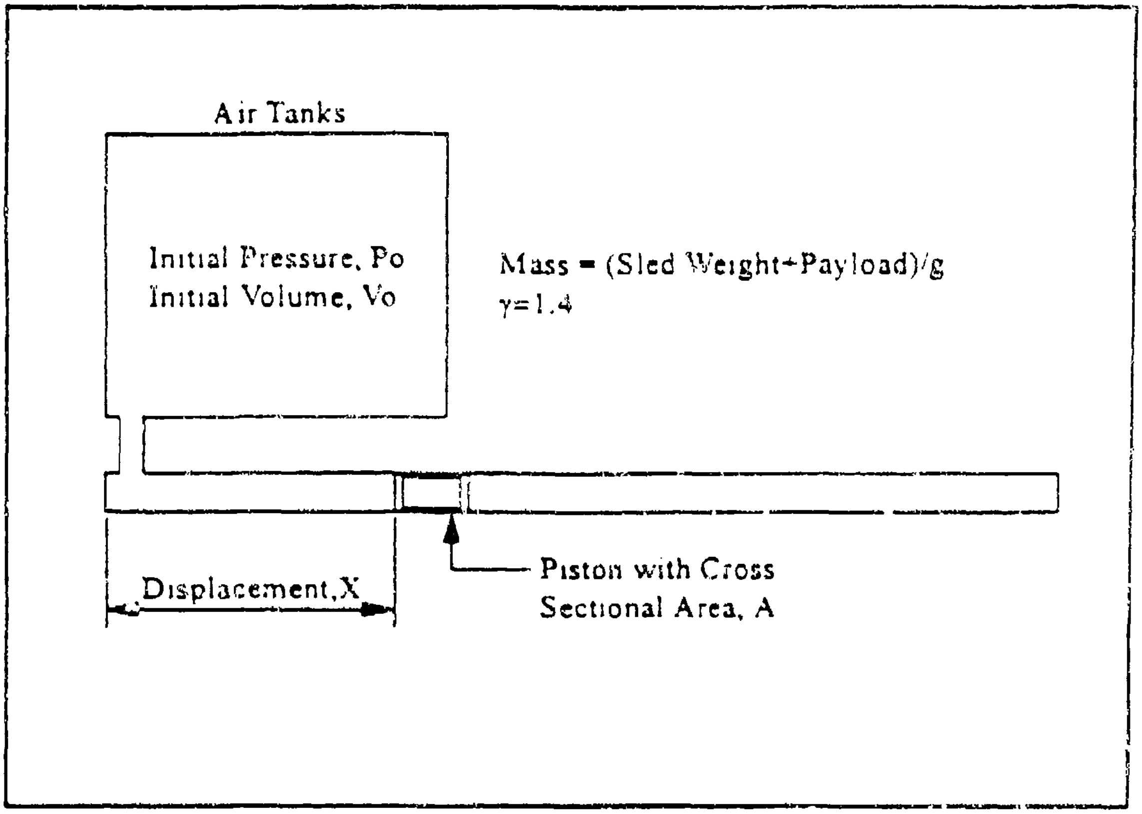


Figure 4.5.2
Schematic of Propulsion System When Control Valves are Open

From the free body diagram in figure 4.5.1 the forces acting on the sled and piston system can be summed. This summation will lead to an equation for the acceleration of the sled that can then be integrated. The force of atmospheric pressure acting either side of the piston has been neglected. The reasons for the omission of this force will be explained at the end of this section.

$$\sum F = m\ \ddot{x} = p\ A - (F_f + \text{Loss}) \qquad (4.5.1)$$

To determine the pressure acting on the piston it will be assumed that the air in the pipe is performing an adiabatic expansion. The equation for this situation is shown below.

$$pV^{\gamma} = \text{constant} \qquad (4.5.2)$$

If the initial conditions for the tank pressure and volume are used, this expression will yield an expression for pressure.

$$p \cdot V^{\gamma} = p_0 \cdot V_0^{\gamma} \qquad (4.5.3)$$

The volume at a given distance down the track, or x displacement, is the initial volume of the tanks plus the volume of air in the pipe. The volume of air at any x displacement is;

$$V = V_0 + A \cdot x \qquad (4.5.4)$$

The expression for the pressure force acting on the piston at any given location can be found by solving equation 4.5.3 for pressure and substituting equation 4.5.4 into it.

$$p = p_0 \cdot \left(\frac{V_0}{V_0 + A \cdot x} \right)^{\gamma} \qquad (4.5.5)$$

If this expression for pressure is inserted into equation 4.5.1 and acceleration is solved for, all that is needed are the initial conditions and the sled velocity and displacement over the delay time can be determined as a function of time.

$$\ddot{x} = \frac{p_0 \cdot A \cdot \left(\frac{V_0}{V_0 + A \cdot x} \right)^{\gamma} - F_{friction} - Loss}{m} \qquad (4.5.6)$$

This equation is valid over the interval $0 \le t \le t_{delay}$. The initial condition for this time interval are;

$$x(0) = 0 \qquad \dot{x}(0) = 0 \qquad (4.5.7.a,b)$$

For the second time interval the control valves on the tanks are closed. For this interval the volume of air in the system will only be that volume that is in the pipe. This volume will be the cross sectional area of the pipe multiplied by the sled's displacement. In order to determine an expression for the acceleration of the sled after the valves have closed, several initial conditions are necessary. These conditions, for pressure, volume, and displacement, are listed below.

$$p_0 = p_{t_{delay}} \qquad V_0 = A \cdot x_{t_{delay}} \qquad x_0 = x_{t_{delay}} \qquad (4.5.8.a,b,c)$$

The equation for pressure will become;

$$p = p_0 \cdot \left(\frac{V_0}{V} \right)^{\gamma} \quad \text{or} \quad p = p_0 \cdot \left(\frac{x_0}{x} \right)^{\gamma} \qquad (4.5.9)$$

This equation for pressure can once again be substituted into equation 4.5.1 to determine the acceleration of the sled.

$$\ddot{x} = \frac{p_0 \cdot A \cdot \left(\frac{x_0}{x} \right)^{\gamma} - F_{friction} - Loss}{m} \qquad (4.5.10)$$

This equation is valid over the interval $t_{delay} \le t \le t_{impact}$ and can be integrated to determine the velocity of the sled. Since it is not possible to determine in advance the time at which impact occurs, the displacement of the sled from its starting point to the impact position has been determined. Impact normally occurs 61 feet from the starting position of the sled. The impact velocity is then the velocity, determined from the integration of equation 4.5.10, where the sled displacement becomes greater than 61 feet.

The program "speed" listed in the appendix will determine the impact velocity of the sled for a given system pressure, delay time and sled payload. The program uses the methods outlined above to predict the impact velocity. The acceleration equation is numerically integrated using a fourth order Runge-Kutta scheme to determine the sled's velocity and displacement over both of the time intervals. The pressure loss term has been determined for several common system pressures and is included in the code.

The speed program was used to determine the delay time and system pressure necessary to meet the 31 feet per second required for the 15 G pulse. The pressure loss term was 455 pounds for the 50 psi system pressure. This loss value was determined from previous tests run at 50 psi. Shown in figure 4.5.3 are plots of acceleration, velocity, and displacement versus time. It can be seen from this figure that as the displacement approaches 61 feet the velocity of the sled is approximately constant. This is ideally how the velocity of the sled should look in order for the sled to achieve a state of zero acceleration prior to impact. The code predicted the velocity to be 33.5 ft/s at a distance of 61.1 feet down the track. This velocity is slightly above the prescribed 31 ft/s, but the prescribed velocity is a minimum requirement.

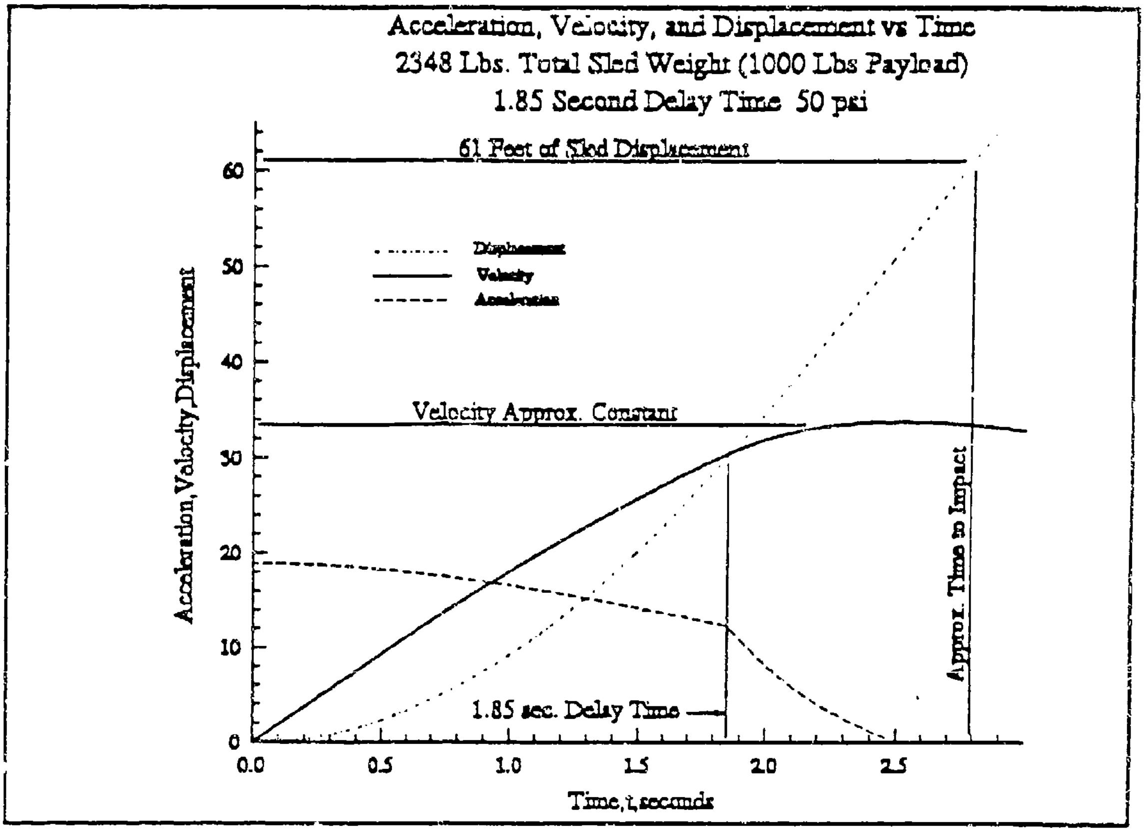


Figure 4.5.3
Sled Velocity Simulation Code Results

The pressure loss term is unique for a particular system pressure P_0. The main component of this loss is the leaks in the pipe. The air will leak at a given rate for a given pressure. It is therefore advantageous to determine any necessary sled impact velocities at

a few specific pressures. Running several impact velocities at the same system pressure will eliminate the need to determine a new loss term for each new impact velocity.

The friction force in equation 4.5.1 has been experimentally determined for several common payload weights. Friction force was measured for the sled and piston with 1000 pounds, 2000 pounds, and no payload. Linear interpolation was used to determine the friction force for other sled payloads.

The method for evaluating impact velocities, as you have seen, does not take into account atmospheric pressure acting on either side of the piston, nor has any attempt been made to include the pressure losses through the pipe joints. The methods developed in this section represent the first attempt that was made to predetermine the sled speed. After this method was developed, several attempts were made to approximate the speed of the sled more accurately. The force of atmospheric pressure on the piston was included, since it is not equal on either side of the piston. An attempt was also made to determine the pressure loss occurring in the pipe. Both of these procedures, though being a closer approximation to the actual system, were never as accurate as the method used in this section.

If a new impact velocity, for a new pulse, needs to be determined it should be done using ballast plates to simulate the mass of the payload. Several speed calibration sled runs should be made prior to attempting a new pulse in order to make sure the velocity in question can be achieved and is repeatable. Determining the parameters for a new speed and pulse separately will save the trouble of trying to figure out whether a propulsion system change or a strap setup change has produced a given change in the impact pulse shape. It is best to only change one variable at a time when creating a new pulse.

4.6) Shaping the Back Side of the Pulse

The pulse up to the peak represents the easiest part to control. The shape of the pulse after the peak G level occurs, however, is often harder to control. This section will examine several methods that can be used to help achieve the best possible pulse shape after the peak G has occurred. The procedures covered in this section represent the methods that have arisen over time. They are not by any means the only steps that can be taken to shape the back side of the pulse, but they are the most common.

As was explained in section 4.3 the pulse essentially has two parts or sides. The front side, the part up to the peak G level, is controlled by the height of the straps, the stance, and the length of the first strap. The back side, from the peak G point on, is controlled by the spacing in between the remaining straps, and the energy left in the system after the peak G level is achieved.

The most critical aspect concerning producing the best back side is having all the straps pull past the idle roller. As the straps pull past the idle roller their load carrying capability will decrease until they pull completely out of the roller cage, at which point the load they will carry will be zero. Ideally the spacing between straps should be such that the straps pull past the idle roller in a manner that causes the sled's acceleration to decrease in the same manner that it increased.

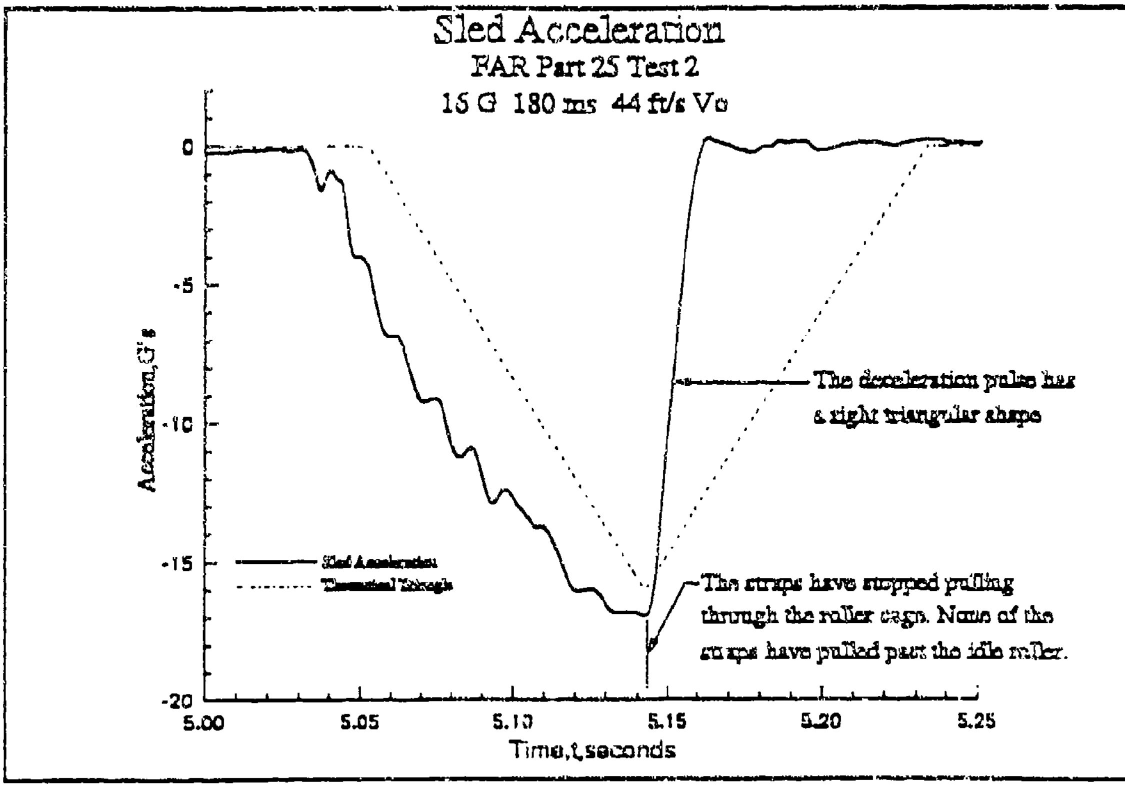


Figure 4.6.1
Pulse with no Straps Pulling Past the Idle Roller

By far the worst possible case for a particular test is for none of the straps to pull past the idle roller. If this happens the shape of the pulse will approach a right triangle. Figure 4.6.1 shows the results of a test where this happened. In this situation a sharp vertical drop off occurs after the peak G level is achieved. As seen from the sample static data in section 4.3, the load carrying capacity of a particular strap will increase as the stroke increases. For this pulse the straps provided an ever increasing resistive force until the energy that the sled had at impact was dissipated. When the impact energy was gone, the sled stopped and the longitudinal acceleration almost instantly returned to zero creating the right triangular shape of figure 4.6.1. The simplest way to eliminate this type of pulse shape is to shorten the lengths of the straps so that they will pull past the idle roller. This may not always be possible, especially if the G level attained was less than or equal to the desired one. If the G level was acceptable much like in figure 4.6.1, the total height of the strap combination will need to be increased. If the height is increased the straps will need to be shorter because the initial slope of the pulse will be steeper. This will cause the peak G level to occur sooner.

On the opposite side of the spectrum is the case where the straps pull too far. This will cause what is referred to as a plateau to appear on the back side of the pulse. A plateau is the result of the sled having excess energy after the straps have pulled through the roller cage. This excess energy exists when the spacing between straps is too small

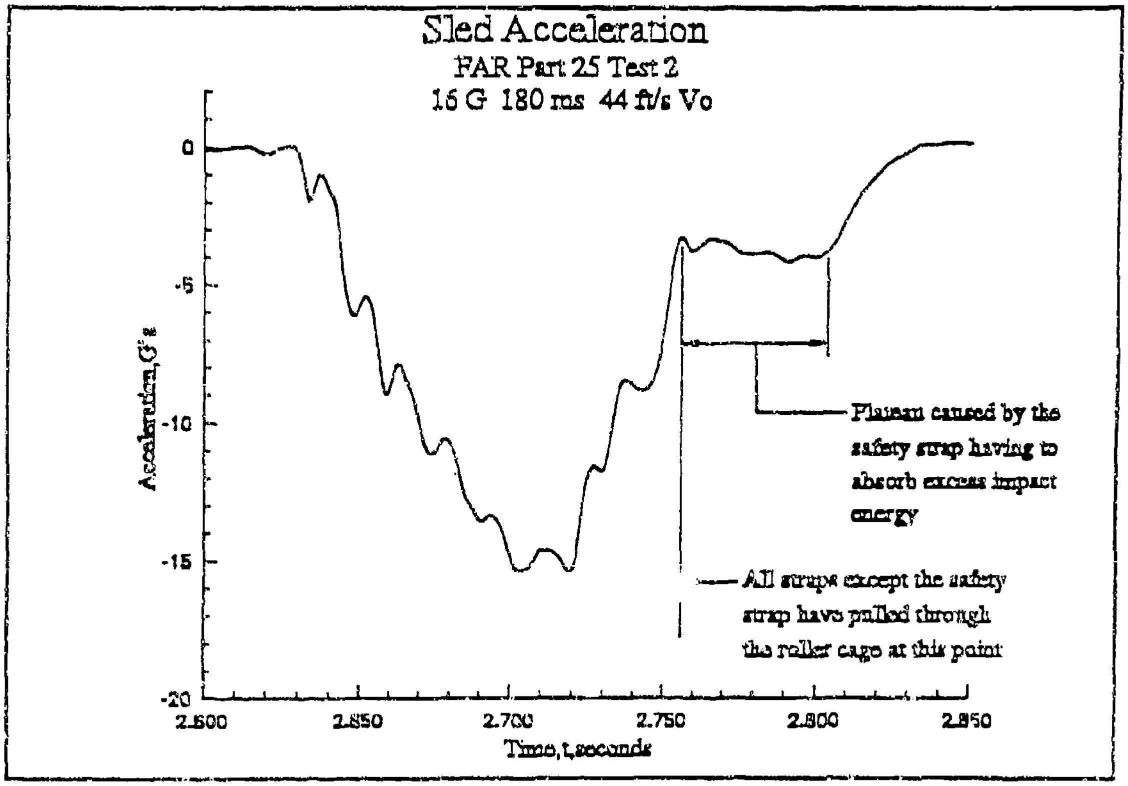


Figure 4.6.2
Plateau on the Back Side of a Pulse

causing the load carrying capability of a setup to drop off too quickly. The safety strap will, in this situation, absorb this excess energy by continuing to provide a resisting force until the energy is dissipated. This situation is shown in figure 4.6.2. The plateau in this pulse occurs at a G level of approximately 3.5, due in part to the size of the safety strap. The G level that the plateau occurs at is directly proportional to the size of the safety strap. The safety strap has therefore been a half inch wide, whenever possible, to minimize the effects of any plateaus that may occur. To remove a plateau from a pulse the spacing between the straps should be increased. This should have the effect of distributing the area under the plateau throughout the entire back side of the pulse. If the straps were all one half inch apart a spacing of one inch may be more appropriate.

As discussed in section 4.3, it is advantageous to use the widest stance possible in order to have the greatest length of strap pull through the rollers. Ideally there is a stance where the straps for a given pulse will pull through the rollers exactly the correct amount. In practice, however, there are a limited number of stances available, and the widest stance available for a given pulse may not allow the straps to pull through the ideal amount. When this occurs the pulse should be developed so that as many of the straps as possible pull at least past the idle roller. This will reduce, as much as possible, the sharp drop off in acceleration that occurs when straps do not pull completely through. Shown in figure 4.6.3 is a pulse where all of the straps pulled past the idle roller but did not pull completely through the roller cage. The G level where this sharp drop off in acceleration occurs is

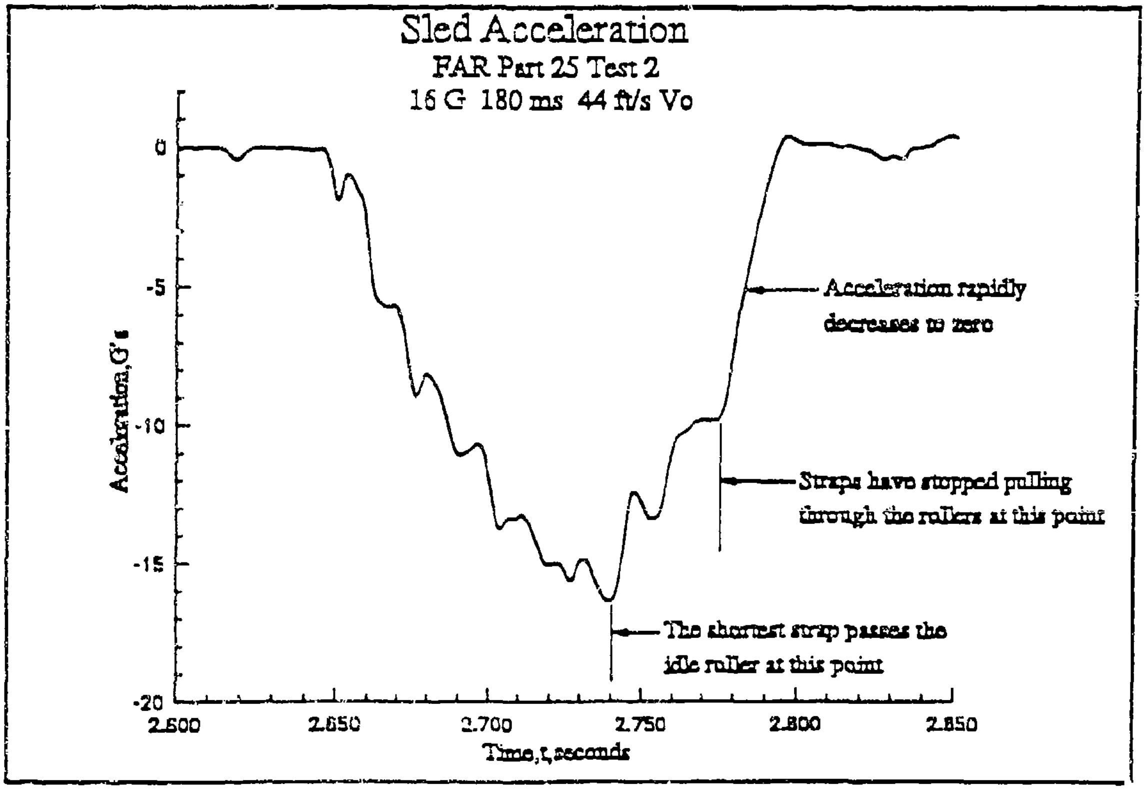


Figure 4.6.3
Straps Pulled Past the Idle Roller but not Completely Through

determined by the location of the straps when the sled's impact energy is dissipated. As was seen in figure 4.6.1, if none of the straps are past the idle roller when all impact energy is dissipated, this drop off will occur at the peak of the pulse. If the straps just pull out as they absorb the last of the impact energy the drop off will occur at zero g's. In practice the straps will end up pulling through somewhere in between these two extremes. The acceleration will then display this characteristic drop off somewhere in the middle of the back side of the pulse much like the pulse in figure 4.6.3. This is not a problem if the overall shape of the pulse is close enough to the desired shape.

4.7) Results from the Sample Pulse

The 15 G pulse that has been developed in the previous sections was run on August 26, 1992. The results obtained from this test are presented in this section. The pulse will be evaluated in accordance with SAE AS 8049 part 5.3.9.2.

The propulsion system was set as determined in section 4.5. The delay time was set to 1.85 seconds and the tank pressure was 50 psi. For this test the weight of the sled payload was 1000 pounds for a total sled weight of 2348 pounds. The velocity that the sled attained at impact was 32.02 ft/s. Since the impact velocity for this pulse is required to be 31 ft/s or greater, this velocity was acceptable.

A plot of the sled acceleration is shown in figure 4.7.1. This figure also shows the ideal triangular pulse. From this figure it can be seen that the peak G level has exceeded the required level of 15. Also noticeable is the small plateau that present on the back side of the pulse, and the point where the straps stopped pulling through the rollers.

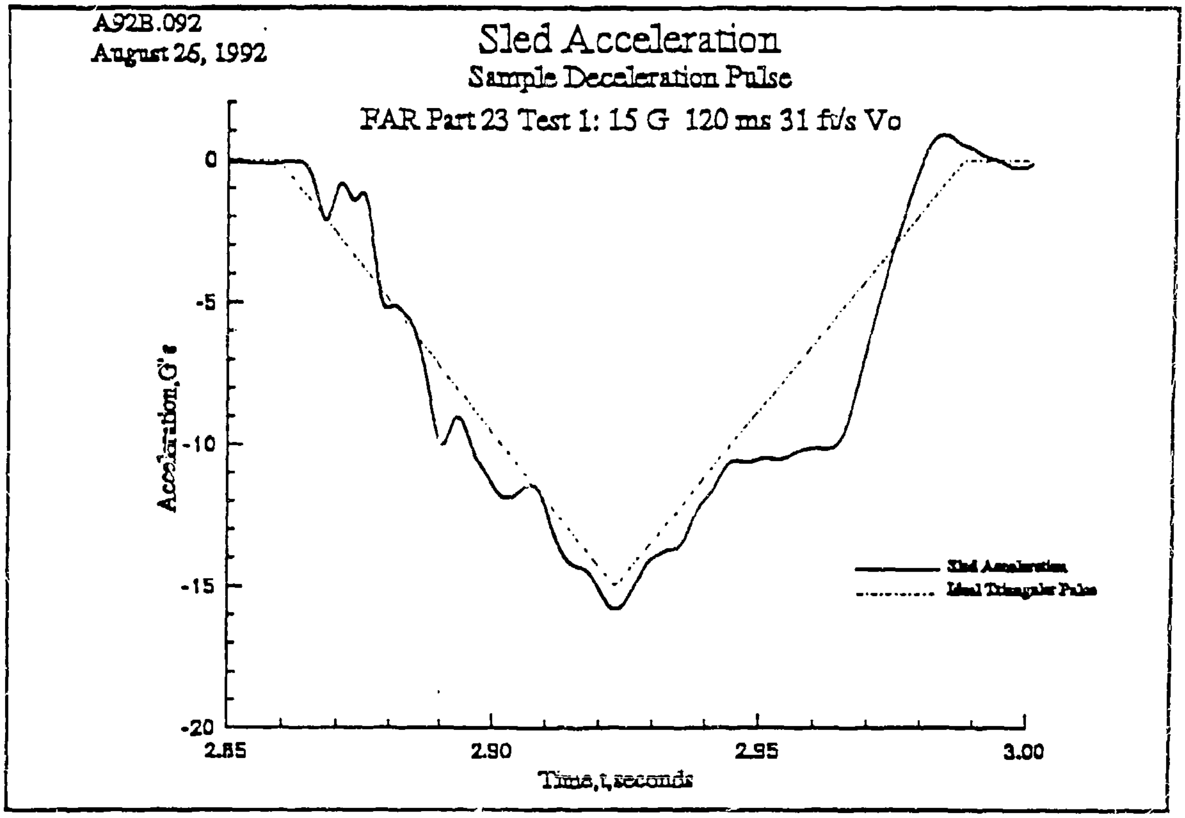


Figure 4.7.1
Acceleration Time History from the Example Pulse

A sample of the data from this test is listed in table 4.7.1. Time, acceleration, velocity, and displacement are listed so that they can be used to evaluate the pulse. When evaluating this pulse the peak G level must be found. From table 4.7.1 the peak G level attained is 15.8014. From this peak G level the ten and ninety percent G levels can be determined. The ten percent G level is 1.58014 and the ninety percent value is 14.22126.

Time, sec.	Acceleration, Gs	Velocity, ft/s	Displacement, ft
2.86030	-.09220	32.03280	60.57270
2.86040	-.08950	32.03240	60.57590
2.86050	-.08670	32.03200	60.57910
2.86060	-.08380	32.03160	60.58230
2.86070	-.08090	32.03120	60.58550
2.86080	-.07790	32.03070	60.58870
2.86090	-.07490	32.03030	60.59190
2.86640	-1.41610	32.01850	60.76800
2.86650	-1.48910	32.01680	60.77120
2.86660	-1.56120	32.01430	60.77440
2.86670	-1.63210	32.01080	60.77760
2.86680	-1.70100	32.00620	60.78080
2.86690	-1.76720	32.00020	60.78400
2.86700	-1.83000	31.99280	60.78720
2.91490	-14.19700	19.70340	62.10930
2.91500	-14.20760	19.65740	62.11130
2.91510	-14.21750	19.61140	62.11320
2.91520	-14.22660	19.56530	62.11520
2.91530	-14.23500	19.51920	62.11720
2.91540	-14.24280	19.47300	62.11910
2.91550	-14.25010	19.42680	62.12100
2.9206	-15.2951	17.0416	62.2140
2.92280	-15.79580	15.92880	62.25020
2.92290	-15.79960	15.87720	62.25180
2.92300	-15.80140	15.82560	62.25340
2.92310	-15.80120	15.77410	62.25500
2.92320	-15.79900	15.72260	62.25650
2.92330	-15.79480	15.67120	62.25810
2.97940	-.10630	-2.40520	62.52760
2.97950	-.05500	-2.40540	62.52740
2.97960	-.00470	-2.40530	62.52710
2.97970	.04470	-2.40500	62.52690
2.97980	.09300	-2.40440	62.52660
2.97990	.14010	-2.40350	62.52640
2.98000	.18600	-2.40240	62.52610

Table 4.7.1
Data from the Example Pulse

The rise time can be evaluated from the times that the ten and ninety percent points occur. The ten percent point occurs approximately at 2.8667 seconds and the ninety percent point at 2.9152 seconds. The rise time is then found from the following equation.

$$\text{Rise Time} = \frac{2.9152 - 2.8667}{0.8} \cdot 1000 = 60.625 \text{ ms} \qquad (4.7.1)$$

By subtracting ten percent of the rise time from the time of the ten percent point, the time zero location for the pulse can be determined. This time is 2.8606 seconds. The

pulse ends when the acceleration versus time curve returns to zero, or at a time of 2.3 times the theoretical rise time past time zero, whichever occurs first. For this pulse the curve returns to zero at a time of 2.9797 seconds, whereas 2.3 times 60 milliseconds added to the time zero location is 2.9986 seconds. This means the pulse ends, for evaluation purposes, at 2.9797 seconds. Figure 4.7.2 shows the pulse with the evaluation lines included.

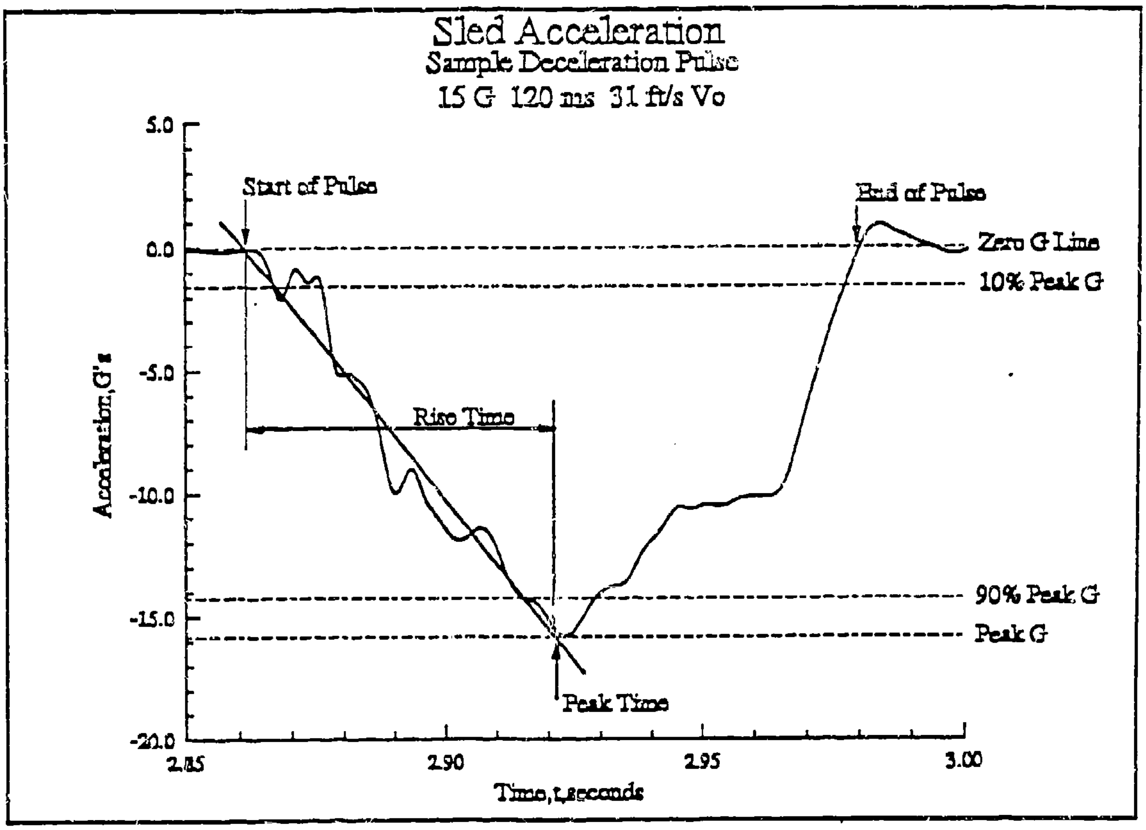


Figure 4.7.2
Pulse with Evaluation Lines

The velocity change requirements can be evaluated once the time zero and ending times are known. The velocity change during the rise time is the difference between the velocity of the sled at the time zero location and a time equal to time zero plus the theoretical rise time. The total velocity change is the difference between the velocities at the time zero point and the ending time of the pulse. From table 4.7.1 the velocity changes are;

$$\Delta V_{\text{Rise Time}} = 32.0316 - 17.0416 = 14.99 \text{ ft/s} \qquad (4.7.2)$$

$$\Delta V_{\text{Total}} = 32.0316 - (-2.4050) = 34.44 \text{ ft/s} \qquad (4.7.3)$$

The evaluation of the pulse has now been completed and a comparison with the required values for a FAR part 23 test 1 pulse can now be made. Table 4.7.2 lists the pulse parameters along with the required values.

Table 4.7.2 shows that both the rise time and the velocity change during the rise time do not fall in their acceptable ranges. This pulse is therefore not acceptable. In the

next section methods of correcting the deficiencies of these and other pulse parmeters will be discussed.

Parameter	Pulse Value	Required Value
Impact Velocity	32.02 ft/s	> 31.0 ft/s
Peak G Level	15.80 Gs	> 15.0 Gs
Rise Time	60.63 ms	< 60.0 ms
Rise Time ΔV	14.99 ft/s	> 15.5 ft/s
Total ΔV	34.44 ft/s	> 31.0 ft/s

Table 4.7.2
Pulse Results Comparison

Though not needed to determine whether the pulse passes of fails, the force versus displacement curve from this pulse can be plotted against the theoretical one. This will help to show how accurate the process of strap selection using static data was. The force versus displacement curve for this pulse is plotted against the theoretical curve in figure 4.7.3.

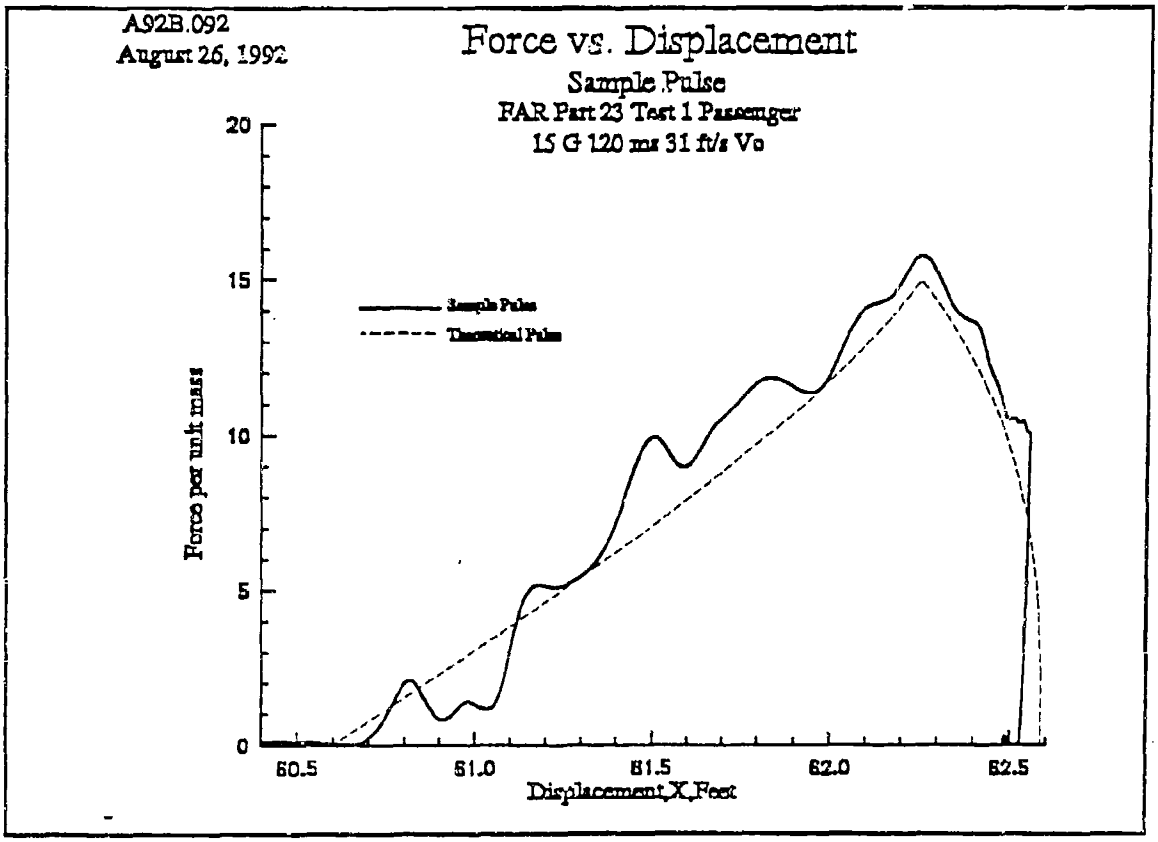


Figure 4.7.3
Force versus Displacement Curves

4.8) Adjusting the Pulse Parameters

A new pulse will usually require adjustments to some or all of the pulse parameters after the first attempt. The four items that most frequently need changing are the G level, rise time, and back side of the pulse, and the impact velocity of the sled. By changing one or all of these parameters the pulse can usually be adjusted enough to pass. Normally the peak G level should be greater than the minimum allowable by no more than ¾ of a g, the rise time should be within ten milliseconds of the maximum, and the impact velocity of the sled should be no more than two feet per second greater than the specified value. The slope of the back side of the pulse should be as close to the slope of the front side as possible for a triangular pulse.

4.8.1) Adjusting the Rise Time

For symmetric triangular pulses the rise time must be less than or equal to half of the theoretical pulse duration. For the 15 G example pulse the peak G level must be attained in 60 milliseconds or less. As was seen in section 4.7 the pulse had a rise time of 60 63 milliseconds. The rise time for this pulse will have to be shortened in order to satisfy the rise time requirement.

There are two methods of adjusting the rise time of a pulse. One method is to change the length of the first strap while keeping the total height of straps constant. The other method is to adjust the height of the strap setup. This will also require changing the lengths of the straps.

Changing the length of the first strap keeps the slope of the front side of the pulse the same but changes how soon the peak of the pulse occurs. Lengthening the first strap causes the peak to occur farther into the pulse, thus increasing the G level and rise time. Shortening the first strap will reduce the rise time and also reduce the peak G level. Changing strap lengths, however, depend on the G level that was achieved by the pulse. If a pulse has exceeded the desired G level by only a few tenths and the rise time is too large, shortening the straps will make the rise time smaller but may also reduce the G level to a point where the peak G level might fall below the required value. If both the rise time and peak G are too small the slope of the front side of the pulse should be extended up to the required G level. This should allow a determination as to whether both the rise time and G level can be met with the strap setup being used. Changing the lengths of the straps is usually an appropriate procedure when both the rise and the peak G level are too large or small.

If the correct peak G level is achieved but the rise time is too large or too small, the height of the strap setup can be changed to modify the slope of the front side of the pulse. Increasing the height of a strap setup will make the slope of the front side of the pulse steeper. This will cause the rise time to be smaller by causing the peak G level to be reached sooner. Conversely decreasing the total height of straps used will cause the slope of the front of the pulse to be shallower. This will make the rise time longer by making the peak G level occur farther into the pulse. If the height of a strap setup is changed, however, the lengths of the straps must also be changed in order to compensate for the peak of the pulse occurring sooner or later.

For the example pulse the peak G level was 15.8 and the rise time was over the maximum value by only 0.63 milliseconds. The lengths of the straps can therefore be

changed to attempt to compensate for this. The peak G level, however, should not be allowed to get too close to the minimum G level. Shortening the straps can be used to reduce the rise time if the peak G level stays far enough above 15.

4.8.2) Adjusting the G Level

If the G level of a pulse is not acceptable the methods of modifying it are the same as for changing the rise time of the pulse. The length of the first strap can be changed or the height of the straps can be changed to cause changes in G level.

The method of changing strap lengths to modify the G level is the same as for changing the rise time. The time to the peak and the magnitude of the peak of a pulse are interdependent when changes in strap lengths are the only changes made. As was mentioned in section 4.8.1, increasing the length of the first strap will increase the G level and shortening this strap reduces the G level.

If the G level is the only thing that needs changing, the height of a strap setup can be changed. A change in strap height will either increase or decrease the peak G level attained over a given rise time. Decreasing the height of the straps will reduce the total stiffness of the strap setup reducing the G level at the peak of the pulse. Increasing the height will have the opposite effect. The strap lengths may have to be modified slightly when strap height is added or removed to keep the rise time the same.

4.8.3) Adjusting the Impact Velocity of the Sled

Changes in impact velocity are usually very minor. There are times when the impact velocity will be slightly greater or less than desired. The main reason for these changes is the condition of the rails. Prior to a test the rails are oiled and wiped but, because the amount of oil on the tracks may not be exactly the same between tests, slight changes in the friction force between the sled shoes and the rails may effect the velocity at impact.

To add or subtract a few feet per second from the velocity, the delay time should be adjusted. An average adjustment in delay time for this type of situation is normally in the range of up to 50 milliseconds.

One other problem that may occur involving the impact velocity is not having a state of zero acceleration prior to impact. This situation can usually be seen on the sled acceleration time history plot. If the velocity at impact is correct but the impact acceleration is non zero, the initial system pressure may need to be changed. The main cause of this problem is often the delay time being too long or short. If the delay time is too long the control valves on the tanks may be closing too close to impact. If the plot of velocity versus time shown in figure 4.5.3 is considered, it can be seen that the velocity will continue to increase for a few tenths of a second before approaching a constant value. When the delay time is too close to the impact time the velocity of the sled will not have the necessary time to approach a constant value. When the delay time is too short the velocity of the sled may be decreasing by the time that impact occurs. As figure 4.5.3 shows, the velocity is approximately constant for only a short period of time.

When the sled acceleration is positive at impact the initial system pressure needs to be increased. This increase in pressure will require a decrease in the delay time. This should increase the time between the delay time and the impact time. Conversely a

negative sled acceleration at impact means the system pressure should be decreased which will require a longer delay time. This will have the effect of moving the delay time closer to the impact time which should move the coasting period into its proper location.

4.8.4) Adjusting the Back Side of the Pulse

It is usually not possible to determine the correct strap setup for the back side of the pulse before the pulse has been run once or twice. For the first attempt the spacing between all the straps is usually some constant value. After the first attempt changes are usually necessary to fix problems that arise with the back side of the pulse. Section 4.6 details some of the most common problems that occur with the back side of the pulse and how to correct them.

4.9) Use of Sled Accelerometers

All of the procedures that have been discussed in section four depend on the proper use of sled accelerometers. A sled accelerometer must be set to properly read the longitudinal sled acceleration in order to determine the pulse seen by the sled. The proper use of an accelerometer includes placement in an appropriate location on the sled, and connecting it correctly to the data acquisition system.

The accelerometer is placed at a point that best represents the average acceleration seen by the entire sled. They are normally placed on the underside of the sled. This keeps the accelerometers out of the way of the payload and protects them from damage. They are also placed along the centerline of the sled because the payload is usually centered on the template. This centerline placement will then give the most accurate representation of the acceleration that the payload is seeing.

Currently the sled accelerometers are placed between the L beams that run longitudinally along the sled, as shown in figure 4.9.1. They are located on the underside of the sled, along the centerline, and at the rear cross member of the sled. The placement at the rear cross member resulted from several tests that were conducted. Accelerometers

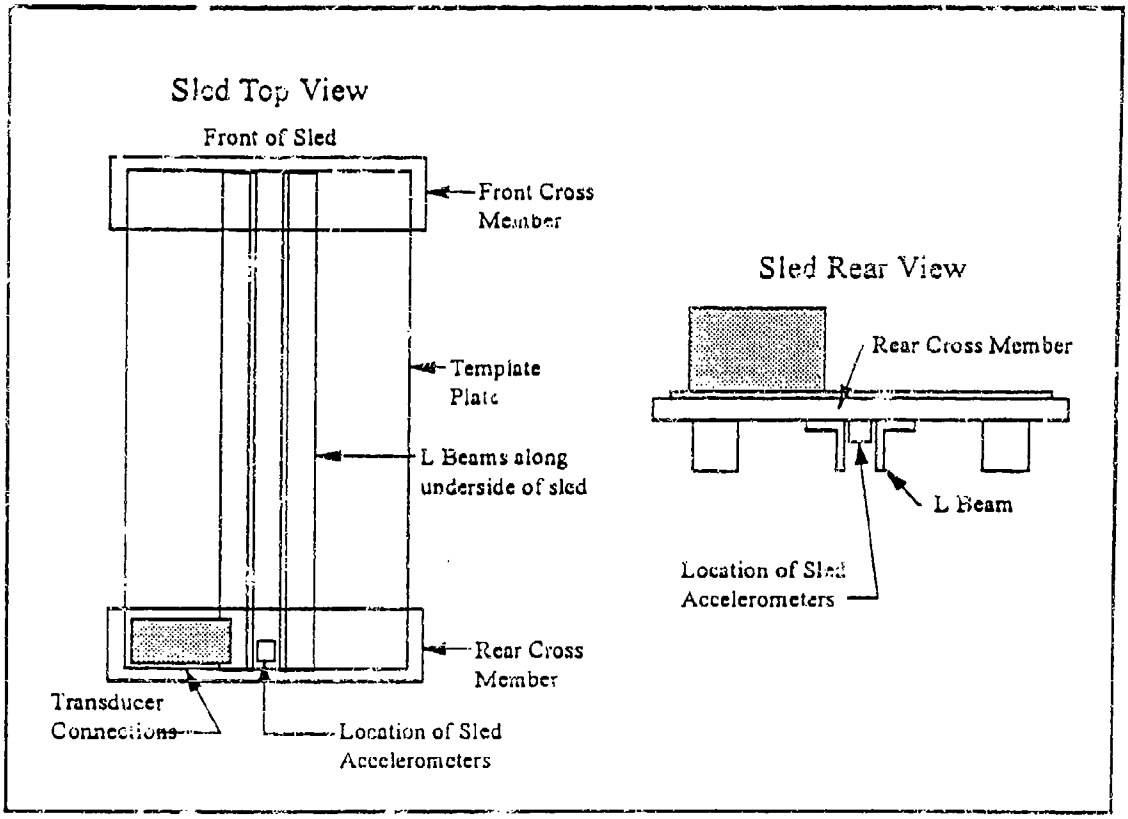


Figure 4.9.1
Location of Sled Accelerometers

were placed at various locations along the centerline of the sled. The readings of those accelerometers were identical but the readings at the rear cross member contained the least noise in the signal.

The accelerometers that are currently used are the Endevco model 7290-30 Microtron, variable capacitance type accelerometers. The procedure for connecting these devices into the data system will be discussed in section five. The main concern is that the excitation voltage and the sensitivity are set right. The sensitivity must be entered into Impax in volts per g, instead of the millivolts per G value provided The excitation voltage is 15 and is set for the particular amplifier the accelerometer is connected to. Each time a new test is run this voltage should be checked since the amplifiers default to 10 volts.

Normally there have been two accelerometers located on the same block under the sled. The second one acts as a back up in case the primary one experiences any problems. The two are mounted into the same holes on the block. Since these devices require a yearly factory calibration, care should be taken to make sure that only calibrated devices are used. Calibration data is often needed to prove the validity of a test. The use of an accelerometer that is over due for calibration could possibly invalidate a test.

The cables that run from the accelerometer to the umbilical interface box should be securely taped down. This will reduce the possibility of cable flailing producing any noise in the signal. This will also help to reduce the possibility of damaging the cables due to someone or something snagging them.

4.10) Comparisons with Other Tests

Normally changes in the deceleration pulse will occur when a strap setup is changed or a new type of payload is placed on the sled. These changes will have to be evaluated and understood. There are several ways of examining changes that have occurred. One method is to compare the results from the pulse evaluation. Another is to examine the shape of the pulse relative to the ideal triangular pulse. Finally the pulse can be compared with previous tests having the same setup and impact velocity.

Assuming only one pulse parameter is changed at a time, the results of a particular change can be seen using the pulse evaluation methods of sections 4.1 and 4.7. This comparison method is useful for determining such things as changes in rise time due to a change in the height of a strap setup, or the changes in G level due to a change in the length of the first strap. If the length of the first strap is the only change, the change in G level that results can be used to determine the change in strap length that will produce a change of one G at the peak of the pulse. This type of empirical information will help in making minor adjustments that may be required for a particular test.

A comparison with the ideal triangular pulse will help to determine how close the pulse has come in appearance to the ideal shape. This is most helpful when examining slopes of the front and back sides. Because the ten and ninety percent points are used in the pulse evaluation, a pulse that has a round peak may pass all the pulse requirements but may not be too close to the shape of the ideal pulse. In this case, overlaying the ideal pulse will help to make a determination as to whether the pulse is close enough to the desired shape. This method also helps in determining whether the shape of the back side of the pulse is satisfactory. Listed in the appendix is the code called "Triangle" that superimposes the ideal pulse upon the test pulse. This code will align the peak of the ideal pulse with that of the test pulse. An example of this capability is shown in figure 4.7.1.

Comparing pulses by overlaying them with other pulses will assist in showing the changes between two strap setups. This is helpful in determining the magnitude of the change in slope of the front side of the pulse when height is either added to or subtracted from a setup. Overlaying pulses will also show the relative change in location and magnitude of the peak of the pulse.

The most valuable information that will come from comparing data with previous tests will be intuitive. Things such as the amount that the G level will change for a given change in strap length will help to develop a feel for the types of changes necessary to fine tune a given pulse. As an example, for the 15 G pulse that has been developed in this section, it has been found that a one inch change in the length of the straps will produce a one G change in the peak of the pulse. This knowledge has in the past been used to adjust the G levels between 16.0 and 15.0.

5.) Performing a Test

In this chapter a description of the steps to follow when performing an impact test is presented. All tests performed at this facility are configured to be in compliance with Federal Aviation Regulations, specifically FAR parts 23,25,27, and 29. In addition, the document AS-8049 by the Society of Automotive Engineers has been used as a guide to establish some of the procedures described here. All requirements and information regarding these test procedures can be found in these regulations and the reader is encouraged to review them.

Chapter five is divided in nine sections. The first six sections deal with preparing the sled for a test run. Section seven describes the procedure to run the sled. The remaining two sections contain information regarding post test procedures.

5.1) Documentation

For each test performed there is a minimum of information regarding system configurations that needs to be documented. This information has been used to build a database that has been useful in the development of deceleration pulses. The information is primarily concerned with the restraining system set up, sled weight, impact velocity, propulsion system settings, and deceleration pulse evaluation results. Figure 5.1.1 shows a sample of the test form used to document sled runs. The first line of the form contains the test number, date, and time when the test was carried out. Subsequently, the form is divided is three parts: pre-event section, post-event section and test description.

Pre-Event Section:

- Weight: Total sled weight. The total sled weight is the empty sled weight, currently 1379 pounds, plus the sled payload.
- System: Refers to the sled propulsion system. There is a primary (Lower) system and a secondary (Upper) system. See section 3.2 for information on propulsion systems.
- System Pressure: Pressure to which the propulsion system tanks are to be filled.
- Probe: Sled probe system being used. For some test both probes are required.
- Stance: Restraining system stance settings. Refer to section 3.3 for stance information. Nominal stance values of 17.25, 32.25 and 52.25 inches are currently being used.
- Roller Cage Position: It refers to the position that the pressure roller is drawn to once its hydraulic cylinder is pressurized. See section 3.3 for details There are two positions, however, position 2 is the only one currently in use. Position 2 corresponds to the distance the pressure roller displaces when pulled by its hydraulic cylinder. This distance is 2.1875 inches. As mentioned in section 3.3, there is a linear transducer attached to the pressure roller that is used to monitored this displacement. The transducer is connected to a digital indicator. The digital indicator shows a reading of 4.02 when the pressure roller is at the zero displacement position. At position 2 the digital indicator will display a reading of 1.82.
- Roller Cage Pressure: Pressure read at the hydraulic cylinder that drives the pressure rollers. It is not being monitored at the present time.
- Straps and Settings: This line specifies the size and length of the straps being used in the restraining system. All dimensions are in inches. Refer to sections 4.3 and 4.4 for

information on criteria for strap selection. Section 5.3.3 describes straps labeling and numbering.

- Accelerometers: Serial number of accelerometers used to measure the sled accelerations. Also shows the channels of the data acquisition system through which these accelerometers are being run.
- Channel Filter Frequency: Specifies the frequency at which the data acquisition system channels are set to. In this data acquisition system raw data is collected if the channel filters are set to a frequency of 2900 Hz. All data collected by this data acquisition system is initially filtered at 2900 Hz, then depending on the channel frequency class (SAE-J211) of the collected signals, each signal is filtered down to a specific frequency. See section 5.5.3.
- Sample Rate: Refers to the data acquisition system sample rate.
- SPS Delay: Indicates the Sled Propulsion System time delay being used. This delay is the time the propulsion system control valves remain open once the sled has been launched. The sled impact velocity is controlled by this time delay and the initial pressure in the propulsion system tanks. Refer to section 4.5 for information on how to estimate this delay time.

Post-Event Section:

- Impact Velocity: It refers to the velocity of the sled when its probe impacts the straps in the restraining system. The sled system is provided with a velocity trap to estimate this impact velocity. It is customary to write down the velocity trap read-out in milliseconds and its conversion to feet per seconds. The velocity trap read-out is the time, in milliseconds, that takes for a one inch wide fin to go across the velocity trap sensor. This fin is installed under the sled on its left side. For more information on the velocity trap refer to sections 5.4.1 and 5.8.
- Stroke: The total sled stroke. This is the horizontal distance the sled travels from the impact position to its final rest position. See section 5.8 for detailed information.
- Maximum G Level: Maximum deceleration level (in G's) the sled accelerometers registered during the impact event.
- Pulse Duration: Approximate deceleration pulse duration in milliseconds.

Test Description:

The test description contains basic information regarding the type of test to be performed, FAA specifications, name of the company for whom the test is being performed, restraining system straps final positions, and any information concerning post impact observations. Refer to section 5.8 for more information.

In addition to the test form described above, a summary of the deceleration pulse evaluation is included in the database. This summary contains the values of maximum peak "g" level, rise time, velocity change during rise time, and total velocity change during the pulse. The information for this summary is the output of the code XL31 developed to evaluate the deceleration pulses according to SAE-8049 guidelines. For information on XL31 refer to section 5.9.2. A plot of the deceleration pulse is also included.

NIAR SLED DYNAMIC TEST

	Test: A93105.002 Date: April 19, 1993 Time: 2:30 p.m.	
PRE EVENT	Weight	2379 Lbs. (1000 Lbs. Payload)
	System	Lower (7.5")
	System Pressure	69 Psi
	Probe	Upper / Lower
	Stance	Upper: 52.25" / Lower: 32.25"
	Roller Cage Position	2 nd
	Roller Cage Pressure	Not Monitored
	Straps and Settings	1,2,3,4= 1.50 x 1/4 5 = 0.5 x 1/4 ; 6 = 1.50 x 1/4 L1 = 91 ¾" L2 = 92 ½" L4 =94 ¾" L3 = 93 ¾" L5 = ∞ L6 = 54" (Lower Restraining Sys.)
	Accelerometers	AC5C9: Channel A01 AM21: Channel A02
	Channel Filter Frequency	2900 Hz
	Sample Rate	10 000 Hz
	SPS Delay	1.68 sec
POST	Impact Velocity	1.87 ms = 44.56 fps
	Stroke	27 in.
	Maximum G Level	21.6
	Pulse Duration	110 msec

Test Description

- 120 ms, 21 G's Pulse (FAR Part 23. Test 2 - Passenger).
- 60° Pitch set up, Cessna toilet seat
- Upper and Lower probes set 24" apart.
- Straps 1-3 pulled up to pressure roller. Strap 4 touching roller next to idle roller. Strap 6 pulled completely through.

Figure 5.1.1
Test Documentation Form

5.2) Preparing the sled

When preparing the sled to perform a test, there are five aspects to be considered. They are sled surface cleaning and oiling, exercising the sled, determining the mass of the payload, securing of test articles and ballast weights, and aligning the sled probe. It is important that all these aspects are covered before launching the sled. It is also recommended to follow the sequence presented here when going through each one of these steps.

5.2.1) Sled Surface Cleaning and Oiling

The sled cleaning and oiling is limited to the sled template. The sled itself is composed of the sled template and its support structure. The template, which is the plate where the test articles are loaded, presents a six by six inch hole pattern. These half inch diameter holes are used to attach all kinds of fixtures, rigs, and payloads to the sled. In order to avoid permanent damage to the holes, it is important that they are cleaned and oiled regularly. Before ballast weights and test articles are added to the sled, it is recommended that the holes on the template be blown with high pressure air to remove particles that accumulate in the threads. Once all holes have been cleaned, synthetic oil such as WD-40 should be applied to provide lubrication. As the process of cleaning and oiling is carried out particular attention should be given to detect cracks or similar damages on the sled surface. If any serious damage is detected corrective action should be taken before loading any test article.

5.2.2) Exercising the Sled

When performing a test, the sled needs to be exercised if no previous test has been run on that same day. Exercising the sled is the process of placing the sled in the launch position and slowly moving it down the track by applying pressure to the propulsion system. The reason for this is to "shake up" all the components of the sled propulsion system before attempting a test. The procedure to exercise the sled is as follows. The sled is pulled back to the launch position at the east end of the track. If any test article or ballast weight is already installed on the sled, check for loose parts and make sure that every item is well secured. Oil the rails on both sides of the track using a small amount of synthetic oil and wipe them dry with paper towels. For safety reasons, load up two 2x1/4 inch straps of full length in the upper restraining system and slightly close the clamp and roller cages. Figure 3.3.1 shows the location of these cages. If, when exercising the sled, it reaches as far down the track as the restrain system, the straps will prevent it from going any farther. Next pressurize the tanks of the main propulsion system (large piston system). For a sled payload of 1000 pounds pressurize the tanks to 18 psi. Proceed then to manually exercise the main propulsion system control valves. The valves, shown in figure 3.2.1, are located on top of the air tanks of this propulsion system. There are two sets of valves. To exercise them, open and close them continuously for about 20 seconds. Do one set of valves at the time. Do not open both valves at the same time unless you are ready to move the sled. When ready to exercise the sled, make sure that the floor area next to the track is clear and inform all personnel in the lab that the sled is about to be exercised. Open the safety valves first, then open the firing valves to move the sled. Let the sled gain some velocity and when it is half way down the track, about 30 feet from launching

position, close both sets of valves. The sled should come to rest before it reaches the restraining system. Pull the sled back to the loading position. If not already on the sled, the test article can now be loaded. The sled does not need be exercised again after the first test has been performed.

5.2.3) Determination of the Mass of the Payload

In this facility, deceleration pulses have been developed for specific sled payloads. These payloads are 1000,1500 and 2000 lbs. Regardless of the type of payload, the total payload is always equal to one of these three ideal weights. For example, if a test article weighs 750 pounds, then 250 pounds of weight are added to the sled to ballast it up to 1000 lbs. For any test it is important to keep the actual payload weight as close as possible to the ideal weight. Payload weights that are off by as few as 15 pounds can cause significant changes in the sled's impact velocity. Impact velocity changes will in turn affect the deceleration pulse shape. To determine the ideal weight to run a test at add up the weights of all of the fixtures, transducers, ATDs, and test articles to be used. The sled should then be ballasted up to the next closest ideal payload weight.

5.2.4) Securing the Test Article and Ballast Weights

It is customary to install the test article on the sled first. If ballast weight is to be used, it is loaded around the test article in locations that will not interfere with the performance of the test article or the ATD. The ATD is usually the last item to be loaded on the sled. The test article, ballast weight, as well as any other item that is installed on the sled needs to be well secured. Time should be taken to verify that all fasteners holding the test articles, fixtures, and ballast weights are well tightened. The obvious reason is safety. In addition to safety, movement of parts on the sled during the impact can cause changes in the shape of the deceleration pulse. Clearly parts of items, like ATD extremities, can not and must not be restrained, however, fixtures, weights and other similar items can be well secured to prevent their movement.

According to the FAA regulations, there are two types of tests to be performed when certifying a test article. For test 1, the test article is installed on the sled with a ten degree yaw angle with respect to the longitudinal axis of the sled. For test 2 the test article is installed with a sixty degree pitch angle with respect to the horizontal plane of the sled.

For test 1 a flat template plate with a three by three inch hole pattern, shown in figure 5.2.1, is used to provide the test article with the required ten degree yaw angle. The weight of the template should be included as part of the test setup when estimating the weight of the payload. It is important to make sure that all of the available bolt holes are used and that the bolts are well tightened when the template is mounted on the sled. For this test an additional requirement is present. The test article must be submitted to a floor warp deformation where one side of the seat is pitched ten degrees and the other is rolled ten degrees. Pitch and roll fixtures have been fabricated for this purpose. These fixtures, called the warping fixtures, are used in combination to provide the test article with the required floor warping effect. They are attached to the ten degree yaw template and the test articles are installed on them. Once the test article is installed and secured, the warping fixtures are deformed to produce the deformation of the test article. It is advisable to perform this procedure as one of the last steps before launching the sled.

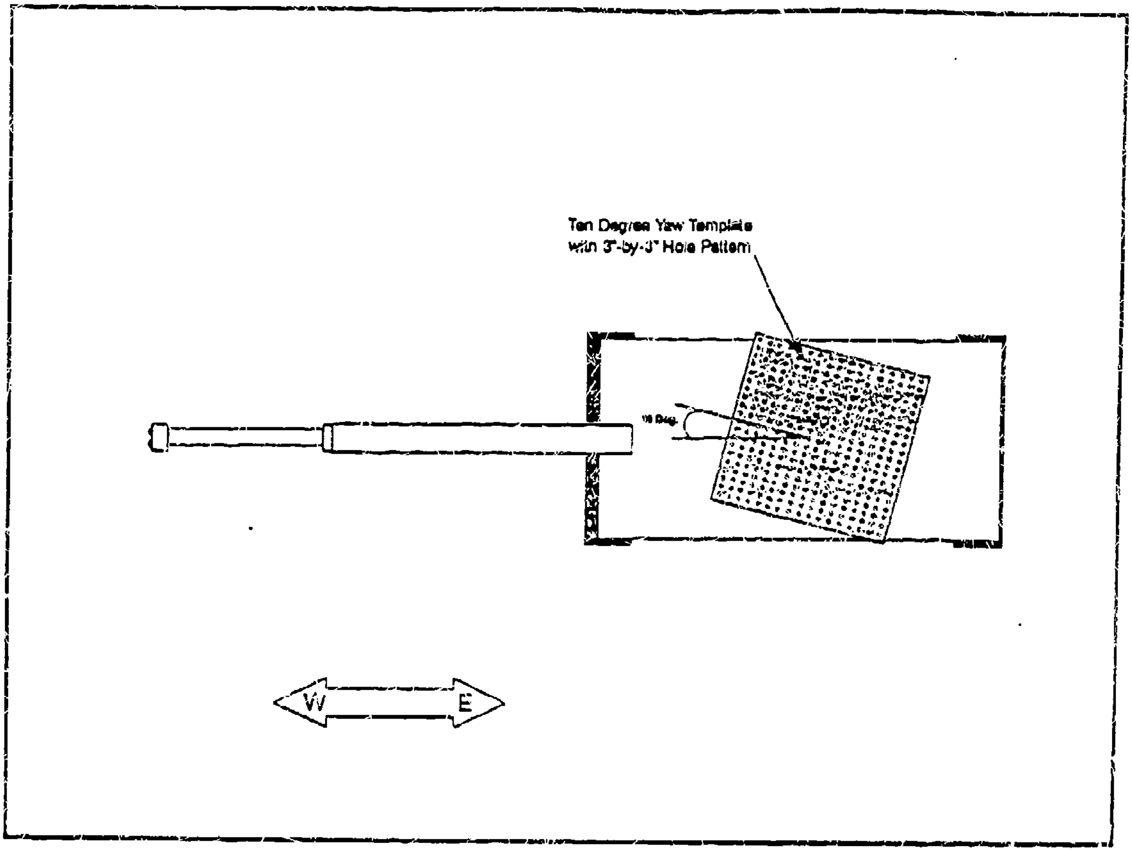


Figure 5.2.1
Ten Degree Yaw Template on Sled

For test 2 a fixture that provides the test article with the required sixty degree pitch angle is installed on the sled template. Figure 5.2.2 shows this fixture on the sled. As for the ten degree yaw template, this fixture is bolted to the sled and must be tightly secured. For this test, due to the dimensions and shape of the sixty degree fixture, the fixture must be loaded with ballast weight and a trial test run to secure the sixty degree fixture in place. The procedure consists of loading either one of the two sixty degree fixtures, depending on what the test article requires. There is a wide and a narrow version of this fixture. The fixture is then placed in position and bolted down to the sled template making sure all bolts are well tightened. For the narrow fixture load 250 pounds of ballast weight. If the wide fixture is used 500 pounds of ballast should be loaded. No test articles should be installed on the sled when performing this trial run. Set up the upper or lower restraining system with two 2x1/4 inch straps of full length. Section 5.3 described how to prepare the restraining system. Once the restraining system is prepared and the fixtures and weights are secured, pulled the sled back to the launching position. The sled is now ready for the trial run. Normally no information regarding this run is saved on the records, however, the sled's impact velocity and peak deceleration are monitored. This information is used to obtain an estimation of the magnitude of the forces applied to the sixty degree fixture at impact. Refer to sections 5.8 and 5.9 for information on how to determine the impact velocity and peak deceleration of the sled. When performing the trial run, it is desirable to

obtain a peak deceleration of approximately the same magnitude as the one specified for the intended test, however, a peak deceleration of about 15 g's will probably provide enough force to secure the sixty degree fixture in place. Based on the sled payload, the sled operator should determine what impact velocity is needed to achieve the desire peak deceleration. Once the trial run is carried out pull the sled back a few feet away from the restraining system and unload the ballast weight from the sixty degree fixture. At this point test article and other rigs can be installed on the sled.

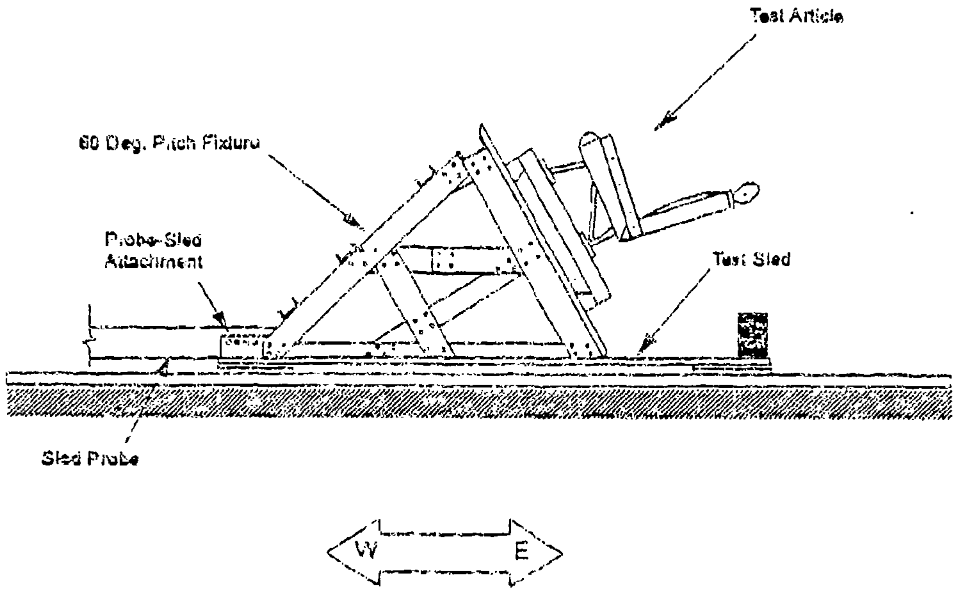


Figure 5.2.2
Sixty Degree Pitch Fixture on Sled Template

5.2.5) Checking the Probe Alignment

When the upper probe engages the straps in the restraining system, there exists a close tolerance between the head of the probe and the lateral cross member of the restraining system (Figure 5.2 5). Due to the nature of the restraining system and the high loads to which probes are subjected during an impact, the upper probe tends to gradually move down and left after a few runs. This gradual probe displacement causes the loss of alignment between the probe and the lateral cross member of the restraining system. This can cause the tolerances between these components to become dangerously small. A collision between the upper probe head and the restraining system cross member will result if the probe alignment is not kept within proper tolerances It is therefore essential to check the upper probe alignment before every test and take corrective action if needed. The procedures for checking the probe alignment are described next.

It is recommended that the probe alignment check be done at two locations on the track. One inspection should be performed at the impact area with the upper probe resting about three feet from the straps in the restraining system. Another check should be done at the launch position. At either location the alignment check procedure is the same. This check procedure can be divided into three steps.

The first step is to check the vertical alignment of the probe. A steel cross bar is placed across the track in front of the upper probe. Each end of the cross bar sits on the track so that the bar is laid perpendicular to the sled's longitudinal axis. The cross bar is then swept under the probe head. Visually check how close the lower surface of the probe head comes to the upper surface of the cross bar as it is swept under the head. If both surfaces come immediately into contact then a probe alignment is mandated. If the cross bar clears the probe head without contact then no alignment is needed. In most cases, surface contact between the cross bar and probe head occurs, however, if sweeping the cross bar under the probe head can be done with relative ease then probe alignment may be postponed until a later run. Figure 5.2.3 illustrates the cases when probe alignment is mandated and when it may be postponed.

The second step involves checking for probe head rotation. This and the vertical alignment check can be done simultaneously while the cross bar is being swept under the probe head. Stand in front of the probe head and observe if the line of the head's lower surface forms an angle with the top of the cross bar. This situation is shown in figure 5.2.4. If there is a gap like the one shown in figure 5.2.4 probe head rotation has occurred and alignment is needed.

The last step in checking for probe alignment involves a lateral alignment inspection. For this inspection the sled is pushed forward to the impact position. If lateral alignment is needed the left side of the probe head will immediately come into contact with the right side slope of the guide rail on the restraining system. Figure 5.2.5 illustrates this case. The lateral alignment check is only done when the sled is at the impact position.

These alignment checks should be performed after test articles and fixtures have been installed on the sled and the sled is ready to be launched. If it is determined that corrective action is needed the probe must be realigned. This can be done at the impact position or the launch position. The document "HITS Technical Manual" describes the procedures for aligning the probe.

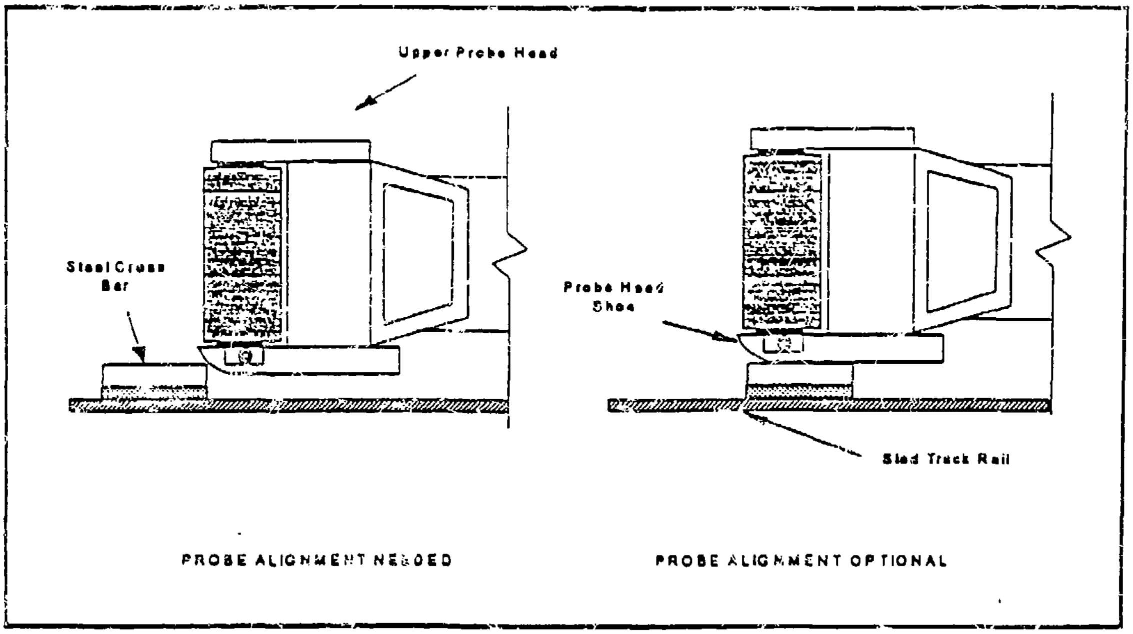


Figure 5.2.3
Sled Probe Vertical Alignment Check

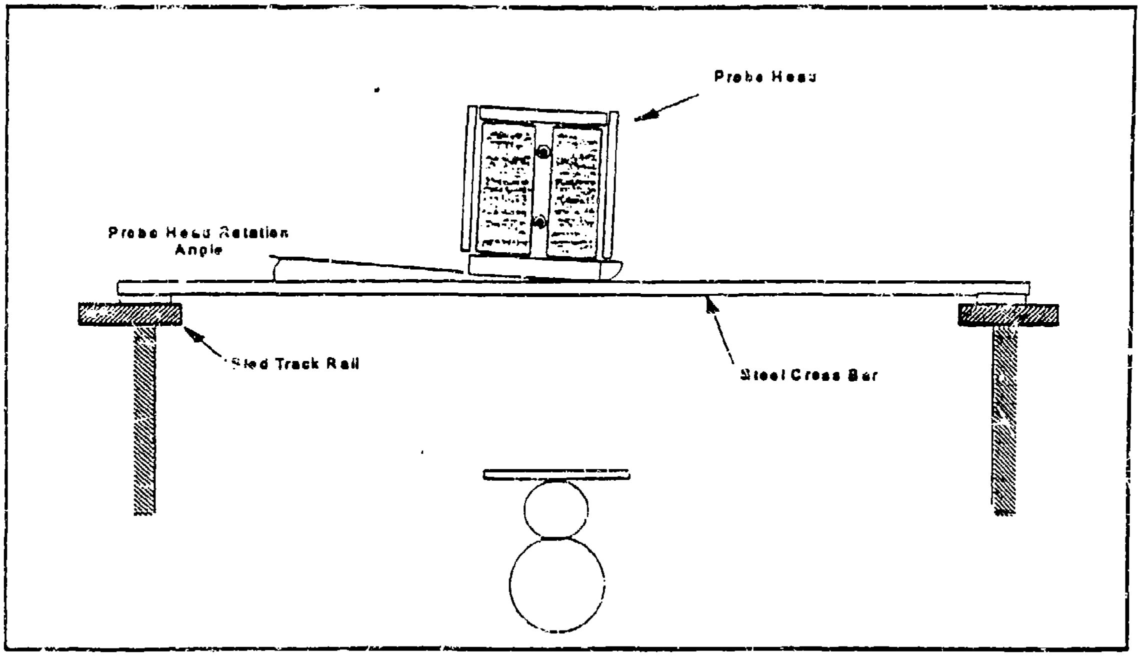


Figure 5.2.4
Sled Probe Head Rotation

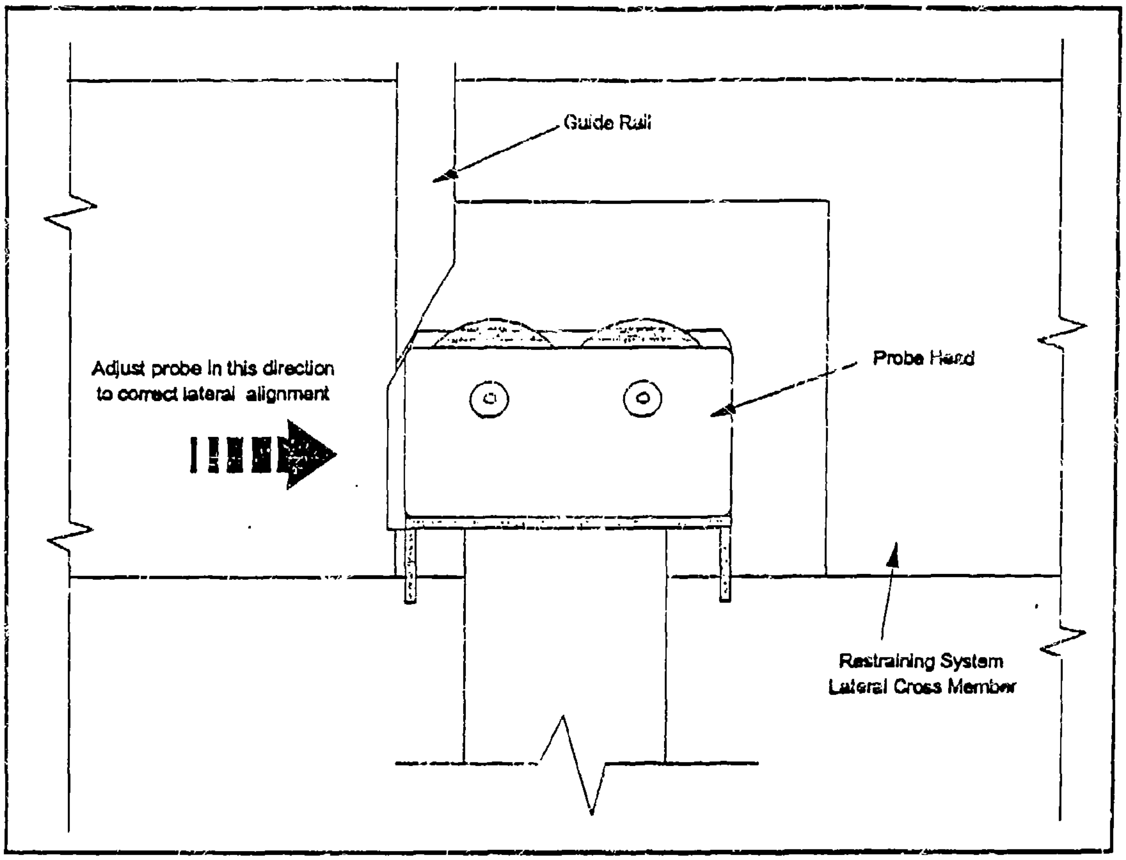


Figure 5.2.5
Sled Probe Lateral Alignment Check

5.3) Preparing the Restraining System

The next step in performing a test involves preparing the restraining system. On the basis of the deceleration pulse required for the test, different adjustments can be done to the restraining system to provide the desired test conditions. This restraining system and its operation are briefly described in section 3.3. There are three procedures to be followed when preparing this system. They are adjusting the stance, checking the cage rollers, and cutting and loading the straps. These procedures are described next.

5.3.1) Adjusting the Stance Setting

Section 4 explains how to select a particular strap configuration based on the deceleration pulse being attempted. When selecting these strap configurations a stance value is chosen. The stance value ranges from 17.25 inches to 52.25 inches. The restraining system roller and clamp cages and their adjoining support columns can be moved laterally to allow for stance adjustment. Figure 5.3.1 shows a top view of these components.

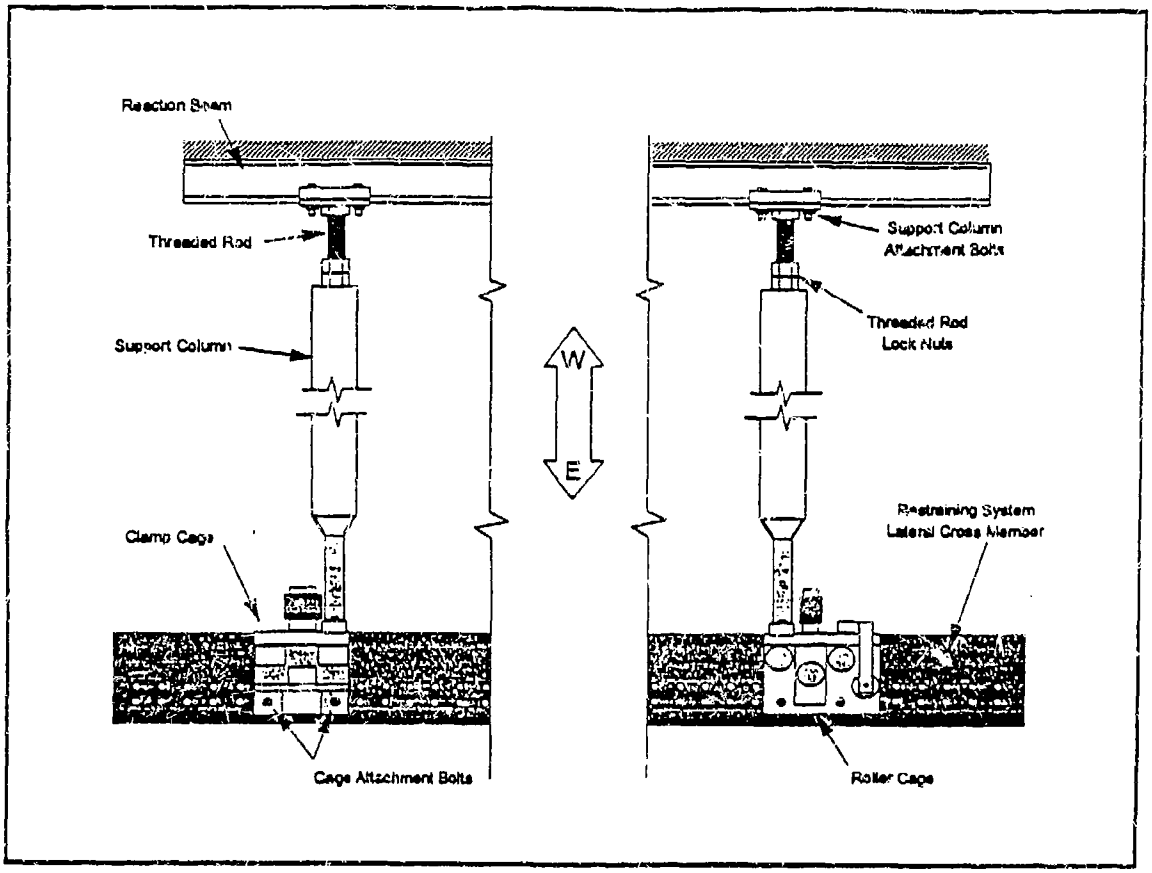


Figure 5.3.1
Restraining System Cage-Support Column Assembly

Starting with either the roller cage or clamp cage, remove the cage attachment bolts. If adjusting the stance of the lower restraining system, place a four legged supporting horse beneath the support column before removing the bolts. Next, loosen the support column attachment bolts and threaded rod lock nuts. At this point the whole cage-support column assembly should be free to move sideways. Depending on the stance setting required, move the assembly in or out by alternately pushing on each end of the support column. Align the holes for the cage attachment bolts with holes in restraining system lateral cross member when the cage-support column assembly is at the desired stance position. This lateral cross member has a hole pattern to provide for different stance configurations. Insert the attachment bolts and tighten them slightly. Move the west end of the support column until it is parallel to the guide rail. To verify this alignment, stand a few feet in front of the restraining system and visually check that the support column is parallel to the guide rail of the restraining system. The guide rail is shown in figure 3.3.1. Apply a torque of 90 foot-pounds to the cage attachment bolts. Verify that threaded rod's west end is in full contact with the reaction beam. If no contact is present, adjustments can be made by turning the threaded rod in either direction. Next proceed to tighten the threaded rod lock nuts and support column attachment bolts. Follow the same procedure for the cage-support column assembly on the other side of the restraining system. Measure

the final stance value to verify that it is as required. The stance is measured as shown in figure 3.3.1. This procedure applies to both, upper or lower restraining systems.

5.3.2) Checking the Cage Rollers

Next step in preparing the restraining system concentrates on inspecting and cleaning the rollers in the roller cages. Refer to figures 3.3.2 and 3.3.3 for details on the roller cage configuration. It is advised that at least once a week the rollers be removed from the cage, cleaned, inspected, and oiled. To remove rollers from the cage remove the all threaded rod, shown in figure 3.3.3, that attaches to the clamp and roller cages. Each one of the four rollers in the cage has some type of attachment that holds it in place. Rollers 2 and 4, shown in figure 3.3.2, contain a center steel cylinder or axis that can be extracted from the top if an attachment bolt is removed. This bolt is located on top of the roller. Once the center cylinder is extracted the roller can be pulled out of the cage. Rollers 1 and 3 are held in place by a steel arm that attaches to their center cylinder by means of an attachment bolt. If the attachment bolts are removed both of the roller's steel arms can be lifted up which will allow the rollers to come out. In this case the roller's center axis stays fixed to the base of the cage. Use paper towels and solvent, if necessary, to clean all of the rollers. Next proceed to visually inspect them. The rollers, 2.5 inches in diameter, have a one inch thick high strength steel wall and a bronze eighth inch thick inner rim or bearing. When inspecting the rollers, look for cracks and any other similar damage in the bronze bearing. In addition inspect the rollers center cylinder for bending and misalignment. Past experience has shown that the idle roller's center cylinder tends to lose its alignment after several runs. If this roller's center axis needs to be realigned, loosen the idle roller base clamp adjustment bolt (figure 3.3.2) and align the axis as needed. If no serious damage is found on the rollers, install them back in the cage. Oil the inner surface of the bronze bearing and the outer surface of the roller's center axis before placing it back in position. A good amount of synthetic oil should be applied to reduce surface friction effects between the roller center cylinder and its bearing. Once the rollers are in place verify that all attachment bolts are installed and tight. Manually spin all rollers in the cage to make sure they rotate easily. This procedure applies to roller cages in both the upper and lower restraining systems.

5.3.3) Cutting and Loading Straps

Cutting and loading of the straps in the restraining system, although an easy task, requires consistency and attention to procedure. To guarantee the desired test conditions strap dimensions and settings need to be as close as possible to the ones specified. This section describes the procedure to set straps in the restraining system.

The straps, which are supplied in twenty foot lengths, are first cut in half. They are then laid on the work bench next to the measuring tape. Since rust and dirt usually accumulate on the straps they should be sprayed with synthetic oil and wiped clean. Set the straps parallel to the measuring tape and using a straight edge move their ends to match the desire strap length. At the opposite end, at the 3 inch mark of the measuring tape, draw a straight line perpendicular to the straps and label it "0." For this purpose use a permanent marker. Label shortest strap as "number 1", the next shortest strap as

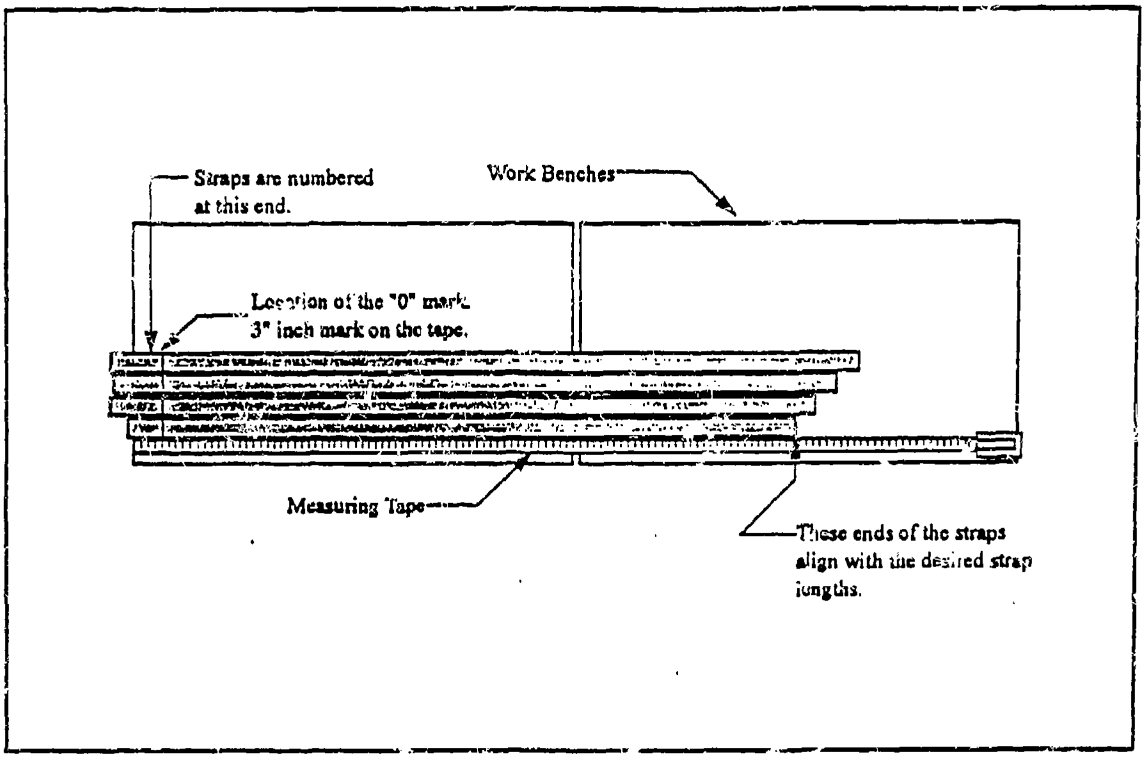


Figure 5.3.2
Strap Marking and Measuring Procedure

"number 2", and so on until all of the straps are labeled. The last strap to be labeled is also called the safety strap and its length is always twenty feet. In the Test Documentation Form, shown in figure 5.1.1, its length is labeled as "∞". This strap is used as a safety measure to help stop the sled in the event of a failure The strap marking and measuring procedure is shown in figure 5.3.2.

Load the straps in the restraining system by first inserting the "0" end of the straps through the roller and clamp cages. The "0" mark on the end of the straps should be facing east, or toward the sled track. Load the straps in reversed order so that strap "number 1" rests on top when all straps are loaded. Next align all the "0" marks with the south edge of the clamp cage base plate. This alignment procedure is shown in figure 5.3.3. It is very important that all "0" marks are aligned with this edge since variations in this alignment can cause changes in the shape of the deceleration pulse. Depending on the total height of the strap arrangement, wooden step blocks may be needed to raise the straps so that they are vertically centered with respect to the sled probe head. There are two of these wooden step blocks and when used, one is placed next to the clamp cage, the other being placed next to the roller cage. It is best to place the straps on the blocks before aligning the "0" marks. Once the straps are in position and aligned they may then be clamped. Close the check valve connected to the hydraulic cylinder of the clamp cage. The check valve is shown in figure 5.3.4. The cylinder is then pressurized until the cage is completely closed. Make sure that the straps are completely deformed and well clamped. Next, proceed to clamp the straps at the roller cage. As previously mentioned, the roller cage is provided with a linear displacement transducer to monitor the travel of the pressure roller when the

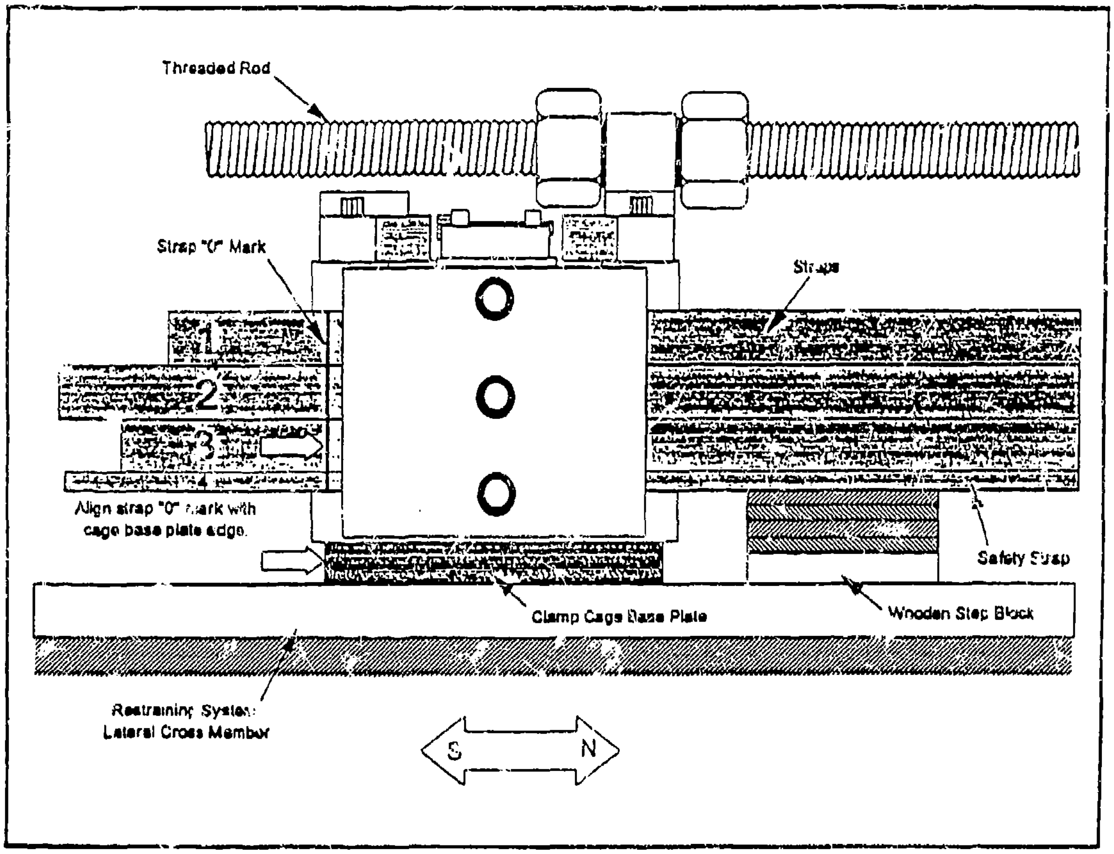


Figure 5.3.3
Restraining System Strap Setting at Clamp Cage

straps are being deformed. Verify that the digital indicator for the linear transducer reads 4.02. If the reading is correct, the check valve for the hydraulic cylinder should be closed. If the reading is something other than 4.02 open the valve and push the pressure roller as far east as possible. Close the valve and recheck the reading on the indicator. If the reading is something other than 4.02, adjust the voltage knob on the power unit until the indicator does read 4.02. Pressurize the hydraulic cylinder until the digital indicator shows a reading of 1.82. This reading corresponds to position "2" of the pressure roller travel. In addition, there is a position "1" that corresponds to an indicator reading of 2.82, however, this position is not currently in use. Figure 3.3.3 shows a front view of a typical strap arrangement in the roller cage. Remove the wooden step blocks if they were used. Using a measuring tape verify the length of the straps by measuring the normal distance from the surface of roller number 2 to the end of each of the straps. This measurement should be taken parallel to the strap's surface. For a restraining system stance of 17.25 inches add 35.0 inches to the measured distance. The total value should be equal to the strap length. If the stance is set at 32.25 inches, add 55.0 inches to the measured length. Add 75.0 inches for the 52.25 inch stance. Spray synthetic oil over the entire strap surfaces to minimize friction effects in the system. As a safety measure, leave the handles on the hand pumps for the hydraulic cylinders in an upright position. This will allow the lab personnel to be able to easily identify whether the restraining system cages are pressurized.

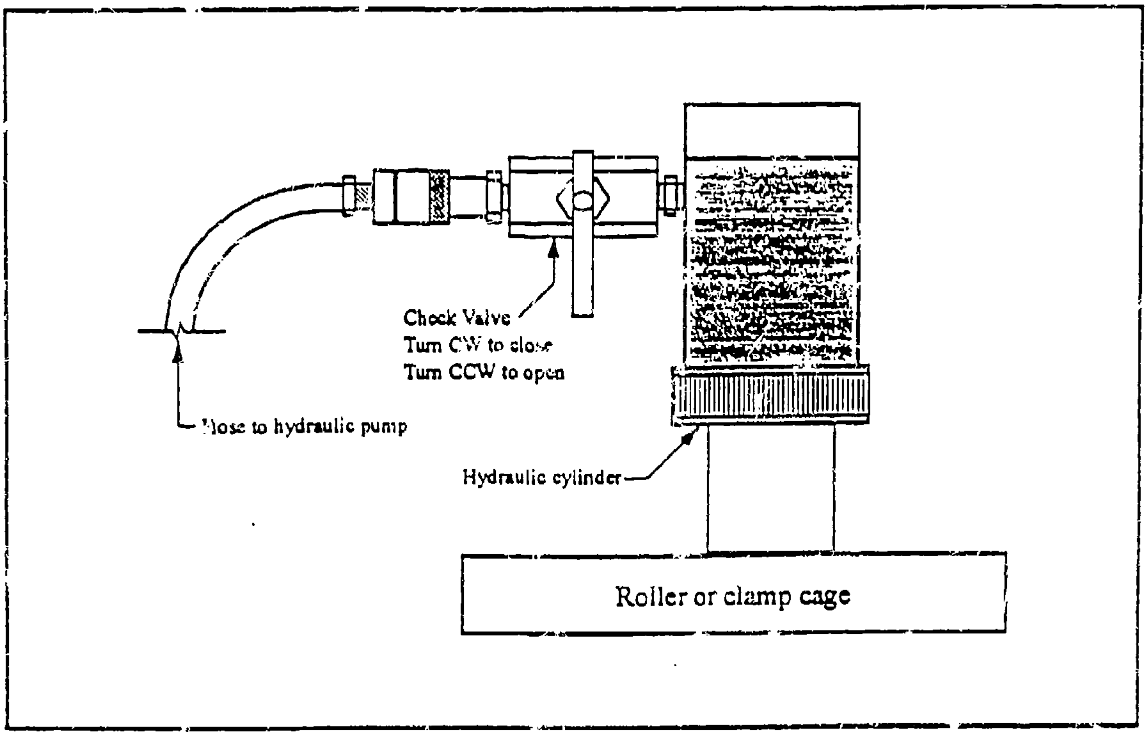


Figure 5.3.4
Hydraulic Cylinder Check Valve

The procedure presented in this section applies to straps being loaded in either the upper or lower restraining systems. Due to the inverted configuration of the lower restraining system no wooden step blocks can be used. For this system the strap vertical centering is done manually.

5.4) Miscellaneous

Once preparation of the sled and the restraining system is completed there are a few other aspects that need to be considered before the sled can be pulled back to the launch position. These include setting the velocity trap and the high speed video camera system.

5.4.1) Setting the Velocity Trap

The velocity trap is a device that measures the velocity of the sled at impact. The device consists of a fork shaped sensor that connects to a control box and of a vertical fin installed underneath the southwest corner of the sled. The control box has an on/off switch, a reset button, and a digital indicator. The sensor sends a signal to the control box when the vertical fin breaks an optical beam. The amount of time the beam was interrupted is displayed in milliseconds on the digital indicator of the box. The reading on the indicator is in units of milliseconds per one inch. It is easy to convert this number into the sled's impact velocity in feet per second.

The fork shaped sensor of the velocity trap is located on the south side of the track a few feet in front of the restraining system. Its position depends on the probe extension.

Some tests require changes in the upper probe length to provide the right test conditions. If adjustments to the length of the upper probe are made, the sensor needs to be relocated to compensate for these probe adjustments.

To set the velocity trap bring the sled up to the impact position. The sled probe should be barely touching the straps in the restraining system. Loosen the attachment bolt at the bottom of the sensor support and move the sensor until the front edge of the fin aligns with the front edge of the sensor. The attachment bolt can now be re tightened. Once the sled is pulled back to the launch position, push the reset bottom on the control box. The digital indicator should read 0.000 milliseconds. Refer to section 5.8 for the procedure used to convert the reading into feet per second.

It is important to always verify that the velocity trap sensor is located at the position that will provide the true impact velocity. If the sensor is not in the correct position the impact velocity reading will be inaccurate.

5.4.2) Camera Setup

At this facility a high speed video system is used to record the impact tests. This video system provides a quick means of reviewing the impact event. The system is composed of two cameras, a video control unit, and a video display monitor. The video system is capable of recording at rates of up to 1000 frames per second. The higher the recording speed the more illumination is needed to provide a clear picture. For this purpose a cine lighting system is used.

The lighting system, which hangs above the impact area, is composed of three identical light banks. Each bank, which has twenty-four 1500 watt lamps, is aligned parallel the track. The middle bank is positioned above the center line of the track and the other two are located on either side of the center bank. The side banks are rotated around their longitudinal axis so that their lamps point towards the test article. This light bank configuration creates a canopy above the impact area that allows for proper illumination of the test article. The lighting system, shown in figure 5.4.1, has a switch board to control number of lamps to be used.

Depending on which test requirements are to be satisfied one or two cameras may be used during a test. One of the cameras is set to record the side view of the test article. The other camera is located above the impact area to provide a top view of the crash event.

Both the lighting and camera systems can be automatically triggered by computer from the control room.

The sled, with test article and ATDs installed, needs to be located at the impact area when setting up the camera system for a test. The head of the sled probe should be touching the straps in the restraining system. Remove any object around the sled that may interfere with the camera's view and pull down the back-drop on the south wall of the lab. Set the video control unit to the appropriate configuration. In particular, check settings for event number, date, camera recording speed, and imagers in use. The latter is very critical. When two cameras are used, both imagers need to be selected under the "System" option. Verify that both channels A and B are highlighted when the selection is made, if both imagers are used. In this menu, the system offers an option that allows the system to

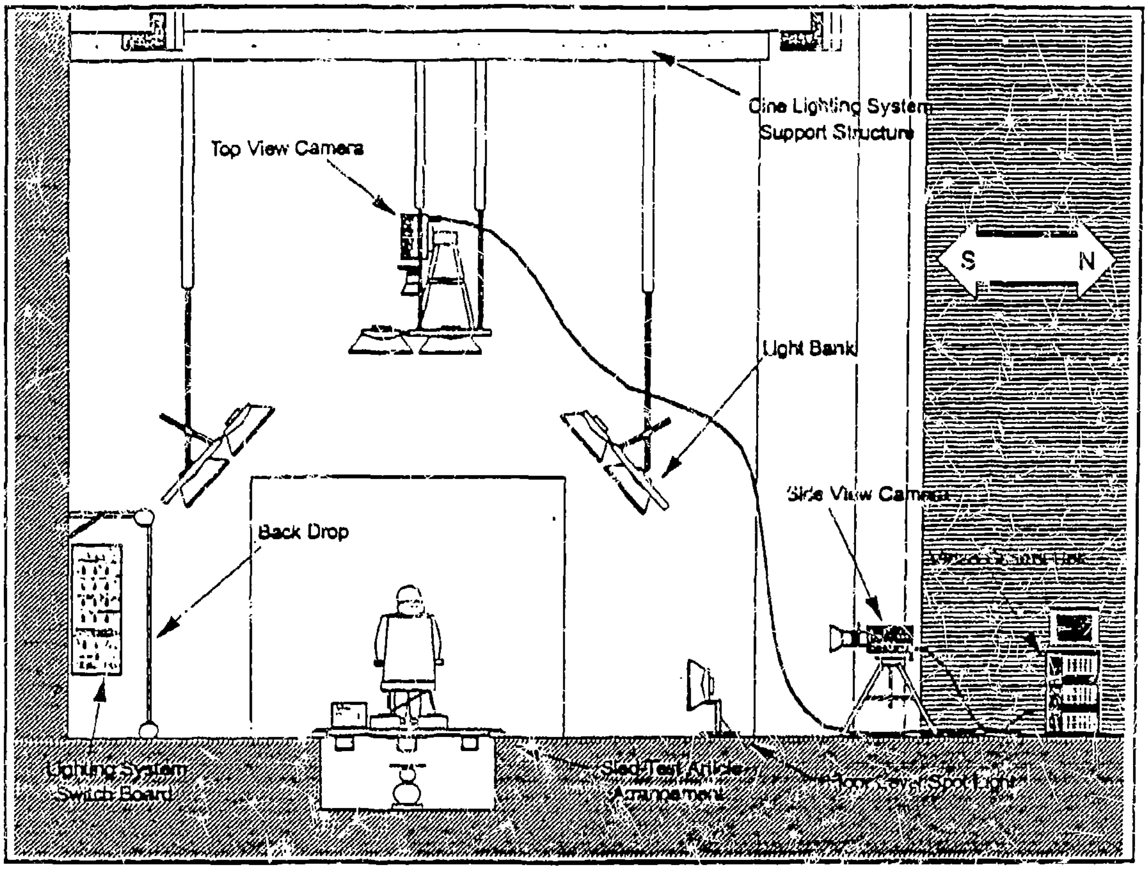


Figure 5.4.1
Cine Lighting System

continuously alternate between camera views while recording. When selecting the two imagers, caution should be taken to not select this option. Refer to the video system manuals for the correct set-up procedure. Camera recording speed is generally set at 1000 frames per second, however, lower recording speeds are sometimes used. Once the video unit is set to the appropriate configuration turn on the cine lighting system. At the switch board there are three columns of switches that allow for different sections of the light banks to be turned on or off as desired. Adjust the aperture and focus settings on the cameras to get the best possible image. This may require trying different configurations of lights. Cameras may have to be moved parallel to the track or nearer or further from the track to accommodate the test article in the camera's field of view. It is important to make sure that the ATDs and test article will still appear in the camera's field of view at the maximum stroke of the sled. Locate the forward most point of the test article. Using a measuring tape move forward by a distance equal to the maximum stroke of the sled and visually check that this point shows in the camera's field of view. Further adjustments in the camera's field of view should be made to compensate for the movement of the ATD's extremities. This is especially important if the forward most point is one of these extremities. A total of 108,000 watts of light is provided if all of the lamps in the cine lighting system are turned on. While adjusting the camera's settings, if the lamps are on for

relatively long periods of time, caution should be taken to avoid overexposing ATDs and the test article to the heat generated by the lights.

The video cameras are equipped with a high gain switch that may be used if illumination from the cine lighting system is not sufficient. In addition floor level spot lights are available to assist with side lighting. Once all of the camera and light settings have been worked out, turn all by-pass switches on the switch board to the enable position. In this position the lights will remain off until just prior to firing the sled when the launch control program will turn them on.

At this point the sled is ready to be pulled back to the launch position. There is a winch and a rope located at the east end of the track that is used to pull the sled back.

5.4.3) Pressurizing the Propulsion System

With the sled in position to be launched, the propulsion system can be pressurized. Before applying pressure to the system, verify that the air compressor on/off switch is on the "on" position. The location of this switch is shown in figure 3.2.1 of section 3.2. A portable warning light system, shown in figure 5.6.1, is located outside the main door of the lab. These lights are used to inform personnel who enter the lab of the status of the propulsion system. The yellow light in this warning system should be on when there is pressure in the tanks of the propulsion system. To pressurize the tanks, turn on the main power switch on the propulsion system control panel and move the vent/pressurize switch to the "pressurize" position The control panel is shown in figure 3.2.3. This action will start the compressor. Tank pressure is monitored with the digital display to the right of the control panel. When the required pressure is reached, turn the vent/pressurize switch to the neutral position and wait until the compressor stops. At this point the pressure in the tanks should be uniform. Use the vent/pressurize switch to adjust the tank pressure if the value on the display does not match the required pressure value.

5.4.4) Oiling the Tracks

In section 3 a brief description of the sled is given. In that section it was mentioned that the sled rides on Delrin plastic shoes that are in direct contact with the rails of the track. The sled manufacturer recommends oiling the tracks with synthetic oil to minimize frictional effects between the shoes and the rails. This will also minimize wear on the shoes. For this reason, synthetic oil is applied to the rails before every test run. It is recommended to perform this process moments before the sled is launched.

To oil the tracks take a paper towel and fold it in four pieces. Thoroughly spray the complete surface of one side with oil. Starting at the west end of the track, wipe the rail surface with the wet side of the paper towel. At the launch position use the towel's dry side to rewipe the rail surface while walking back to the impact position. Repeat the same procedure for the rail on the other side of the track using a new paper towel. This procedure, although rather simple, requires the operator to be consistent with the amount of oil being used to lubricate the rails. The sled's impact velocity is relatively sensitive to the amount of oil applied. If too much oil is used the velocity of the sled at impact may be higher than expected. See section 6.1.1 for further details about the oiling procedure.

After oiling the tracks, use a broom handle to separate the sled tow cables. The purpose of this practice is to prevent the cables from getting tangled. The cables, which

lay on wooden supports evenly spaced along the entire track length, need to be moved outward as far apart as the wooden supports allow. Using the broom handle walk next to the track and push the cables against the outside edges of the wooden supports. This procedure, although not part of the oiling process, is included in this section because it is customary to perform it immediately after oiling the track.

5.5) Impax

The software that controls the data acquisition system is called Impax. Impax is an integrated measurement and control program for multi-channel transient recording. The program, a Microsoft Windows application, is the main tool to process and manipulate test data. It is installed in one of the computers at the lab control room. In this section a brief overview of some of the program's features is presented.

The procedure when running a test with Impax can be divided in two parts, pre and post event procedures. The pre-event aspects of Impax include starting the program, adding transducers to the channels, configuring the channel amplifiers, setting the data acquisition system controller, zeroing and balancing transducers, and monitoring their readings. The post-event part includes processing and storing the collected data. All of the aspects that must be known to be able to perform a test with Impax will be covered in this section. For detailed information, the reader is encouraged to read the "Impax User's Manual."

5.5.1) Starting Impax

From the Microsoft Windows program manager start Impax by double clicking on the Impax icon. On startup the program displays a menu of choices related to the specification of a test name. If a new test is to be created, choose the "New" option in the menu and enter the new test name. If an old test is to be run, choose the "Open" option to

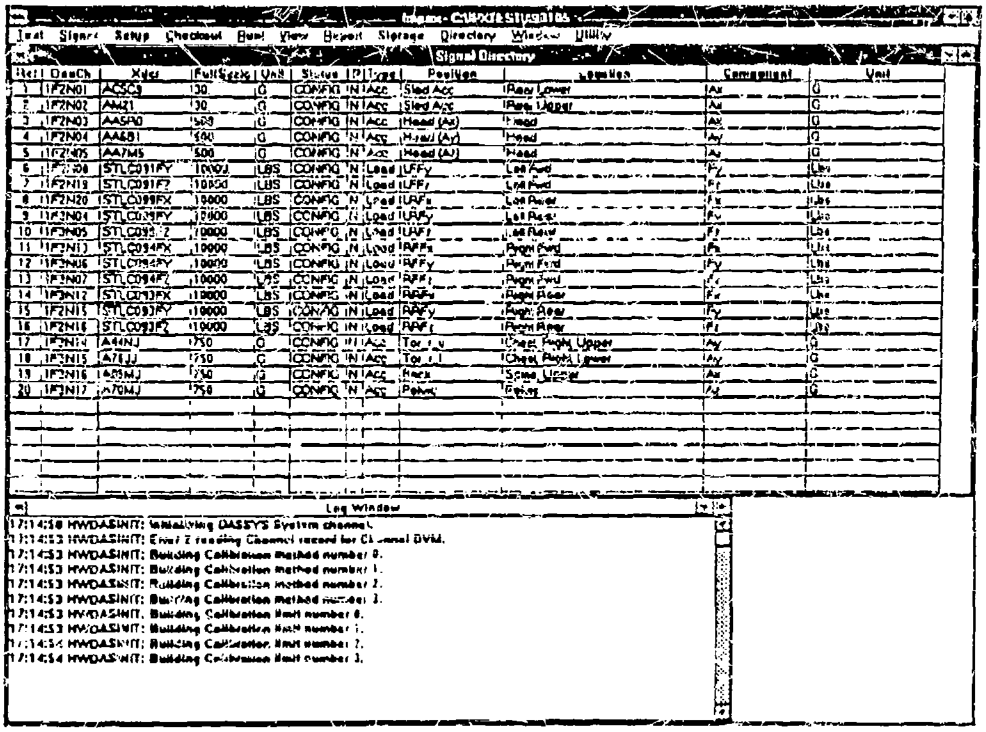


Figure 5.5.1
Impax Main Menu

access the existing test In either case, immediately after a test is opened or created, the program will displays a window with information regarding the test description. The Impax main menu will appear by clicking the "OK" button on the displayed window. Impax sub menus will appear directly below the title bar at the top of the main Impax window. A typical Impax main menu window is shown in figure 5.5.1. The window is divided in two parts, a Signal Directory and Log Window. The Signal Directory contains a summary of information pertinent to the settings of the transducers in use. At this window new instrumentation information and channel settings can be entered and/or changed to monitor the instrument's measurements. The Log Window is used to display the status and intermediate information associated with each Impax operation.

5.5.2) Adding Devices and Calculating Sensitivities

This section will describe how different measurement devices and instruments are assigned to data acquisition system channels through Impax.

When a new test is created in Impax the program main menu looks the same as in figure 5.5.1 but rows in the Signal Directory menu will be empty. To add a new device to the window, click on the "Signal" option of the Impax menu bar. This action should display a menu with the following items: Signal Directory, Signal Description, Process Signal Directory, Amplifier, Converter, and Controller. Click on the Signal Description item and a new window will be displayed. This window contains the signal description form which is used to add all information regarding the measurement device. Figure 5.5.2

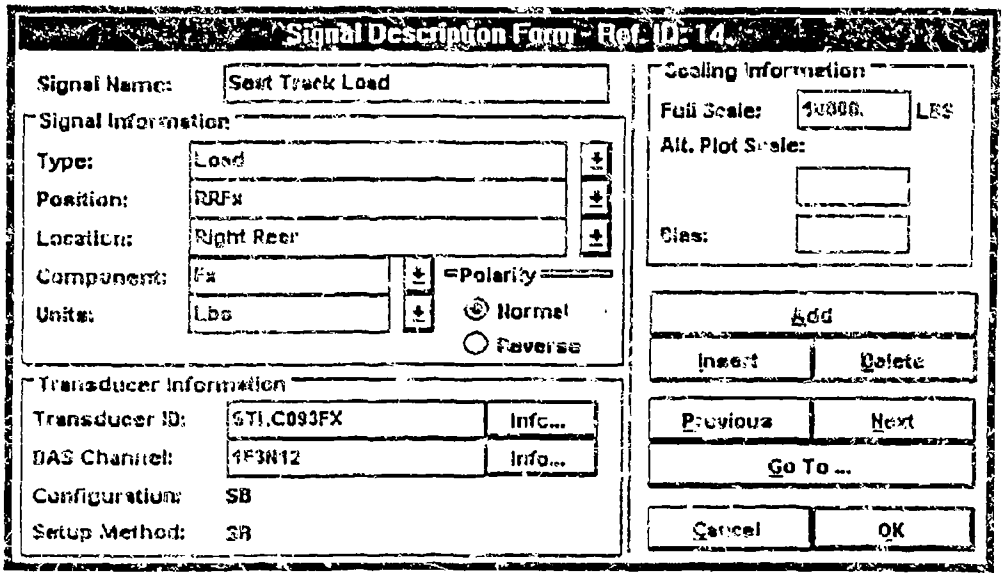
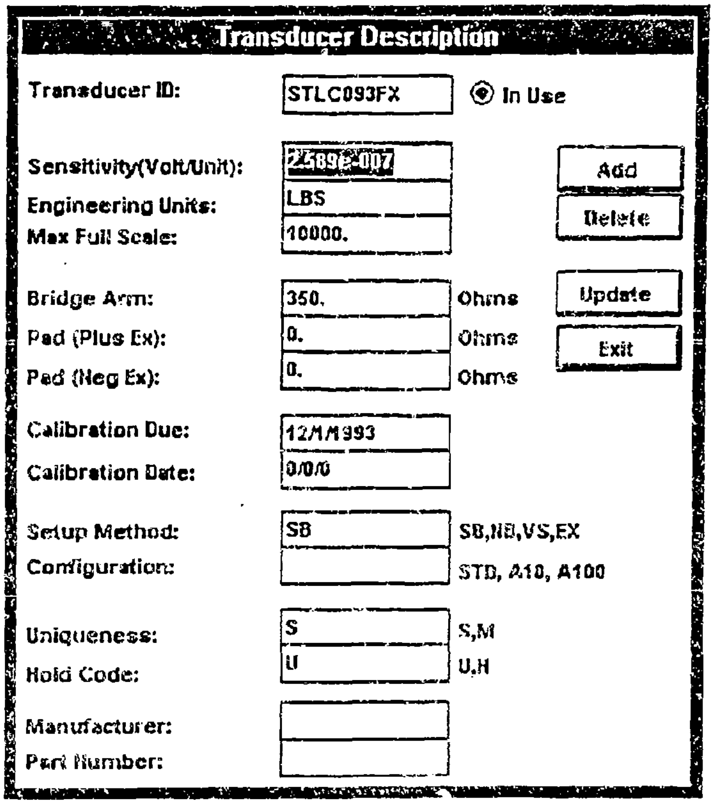


Figure 5.5.2
Impax Signal Description Form

shows this form. The signal description form is divided in three functional groups: Signal information, Transducer Information and Scaling Information. The Signal Information group describes the transducer type, position, location, component, and units. All of this information must be entered. The Transducer Information group determines how a signal is measured. This group includes selecting a transducer identification number and a Data

Acquisition System (DAS) channel. To select a transducer enter its identification number in the "Transducer ID" box. Impax will retrieve the device's information from the transducer database file and add it to this channel specification. Select a data acquisition system channel by entering the channel identification number in the "DAS Channel" box. A sample identification number is 1F3N12. The first digit, "1," refers to the Data Acquisition Unit (DAU) in use. At the present time there is only one unit. The second and third labels, "F3," refer to the crate number, which is three in this case. There are up to four crates per data acquisition unit. The crates are stations into which the DAU is divided. The last three labels, "N12," in the identification number, correspond to the channel number for the amplifier in use. There can be up to 22 channels per crate. This device is connected to amplifier number twelve.

The Scaling Information group determines the measurement range for the signal. In the "Full Scale" box enter the maximum full-scale level expected to be measured with the transducer. The transducers most commonly used at this facility include load cells, accelerometers, displacement transducers, and strain gages. With the exception of strain gages, the transducer's maximum full scale is found in the transducer data sheets. When using strain gages, the expected maximum strain level will have to be known beforehand to be able to specify these limits.


Transducer Description

Transducer ID:	STLC093FX	In Use	
Sensitivity(Volt/Unit):	2.589e-007		Add
Engineering Units:	LBS		Delete
Max Full Scale:	10000.		
Bridge Arm:	350.	Ohms	Update
Pad (Plus Ex):	0.	Ohms	Exit
Pad (Neg Ex):	0.	Ohms	
Calibration Due:	12/1/1993		
Calibration Date:	0/0/0		
Setup Method:	SB	SB,HB,VS,EX	
Configuration:		STD, A10, A100	
Uniqueness:	S	S,M	
Hold Code:	U	U,H	
Manufacturer:			
Part Number:			

Figure 5.5.3
Impax Transducer Description Form

After all of this information has been completed, verify the transducer's sensitivity value specified in the transducer information group. Click on the Transducer ID "info..." box of the transducer information group. This will display a new window that includes a summary of the transducer's specification data. Figure 5.5.3 shows this window. Verify that the transducer sensitivity value shown on the window corresponds to the one specified by the transducer data sheet. Attention should be given to the fact that, in this window, sensitivity values are required to be entered in Volts/Unit. Most transducer sensitivity values are given in millivolts/volts, therefore a conversion is needed. If a transducer sensitivity is given in millivolts/volts, it can be converted to volts/unit by dividing the sensitivity value by one thousand and by the transducer full scale. With the exception of the strain gages, this is the rule that applies for most of the transducers used.

Strain gage data sheets usually include a gage factor that can be used to estimate an equivalent sensitivity value. To estimate the strain gage sensitivity value use the following equation:

$$Sensitivity = \frac{Gage\ Factor}{4e^{-6}} \tag{5.5.1}$$

This estimated strain gage sensitivity value (Volts/μin/in) can be directly entered in the Transducer ID "Info..." menu. In addition to the sensitivity value, other parameters that need to be verified in this menu include transducer full scale, bridge arm resistance, and setup methods. For information on the setup method refer to the "Impax Reference Manual."

After verifying the Transducer ID "Info..." menu, exit this window and close the Signal Description Form. This action will redisplay the Impax main menu on the screen. It will now include the transducer information on the first line of the Signal Directory. This transducer will be referenced as "1" in this menu (see first column of signal directory in figure 5.5.1). Other transducers are added to data acquisition channels by following the same procedure. Additional transducers will be labeled as "2", "3", "4", and so on as they are assigned to the different channels.

5.5.3) Channel Amplifiers

After all transducers have been assigned to a channel, the data acquisition channel amplifiers must be set to match the voltage and filter requirements of the transducers.

All transducer and measurement device signals are conditioned and filtered by the amplifiers in the data acquisition system. There are two types of amplifiers currently being used with this system. The model 1501, referred to as a strain gage amplifier, combines all the functions needed between a transducer and an analog-to-digital converter into a single module. Constant excitation voltage for the bridge is incorporated. Amplifier gain and filter frequency are fully programmable. In addition, internal auto bridge balance and auto amplifier zero functions can be initiated by computer command. These amplifiers are used to monitor signals of full bridge type devices. At the present time the data acquisition unit includes 60 of these modules. The other amplifier, model 1402, is a differential amplifier that presents characteristics similar to the 1501. The amplifier includes programmable amplifier gain and filter frequency, and auto amplifier zero functions. This module,

however, does not incorporate a bridge excitation voltage source. The data acquisition system includes 4 of these amplifiers.

The previous section described how to assign transducers to the data acquisition system channels in order to monitor the transducer's signal. The channel's amplifier needs to be set to provide the required transducer excitation voltage and channel filter frequency levels. To access the amplifier settings, click on the "Signal" option of Impax main menu bar. The "Signal" sub menu will be displayed as described in section 5.5.2. Click on the "Amplifier" item and a new window, shown in figure 5.5.4, will be displayed on the screen. The window is divided in six groups. On the group labeled "Amplifier" the filter box must be selected to enable the amplifier's signal filter. Next to the filter box verify that a filter frequency value of 2900.00 Hertz is displayed. Unfiltered data is collected when the amplifier filters are adjusted to a frequency level of 2900 Hertz. This filter frequency value has been selected for this reason. Data can subsequently be filtered down in accordance with its channel frequency class defined in SAE-J211. The option "Process Signal Directory," in the "Signal" menu, allows for data filtering. This option is explained in section 5.9.1.

In the "Settings" group of the amplifier window the "1501 Active" box must be selected. Next, in the "Excitation" group at the "output" line, enter the required excitation voltage to match that of the transducer in use for the channel. Select the "save" option in the "Defaults" group to store the assigned parameters as default values for this channel amplifier. Select the "OK" box on the right lower corner of the window to exit this menu. The Impax main menu will be on display again. Repeat the same procedure to set each of the channel amplifiers in use.

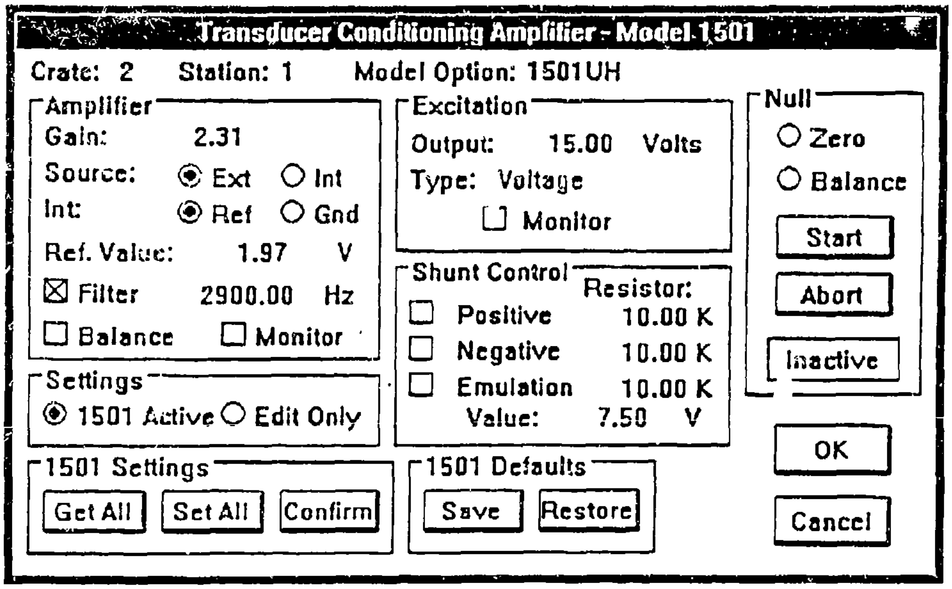


Figure 5.5.4
Impax Transducer Conditioning Amplifier

5.5.4) The Signal Controller

In addition to the signal conditioning amplifiers, the data acquisition system includes what is called the TRAQ system. This system is in charge of acquiring the analog data from the different channel amplifiers, digitizing it and storing it in a local memory. The system is defined by one controller, a memory module and a digitizer.

The system controller is in command of all data acquisition. It communicates with the computer, through Impax, to determine the required sampling rate, pre/post trigger information, number of active data channels, and memory allocation.

In this section, a brief review of how to access the controller's setting through Impax is given. The information regarding this control system is extensive and thorough and can be found in the "TRAQ REFERENCE MANUAL." The reader is advised to review this document for more detailed information.

In the Impax main menu, select the "Signal" option and access the "Controller" item of this menu. Upon clicking on the item, a window similar to the one shown in figure 5.5.5, will be displayed. This window, the TRAQP System Controller, is divided into seven groups. Most of them are self explanatory. At the "Channel" group, the number of channels available in the system is displayed. If for any reason the number of channel amplifiers in the system is reduced or increased, this value should be changed to match the actual amplifier count. The "4012 Active" option in the "Settings" group should be selected to enable the controller. In the "Record Length" group the total amount of data points that can be collected is specified by the record length. This record length can be

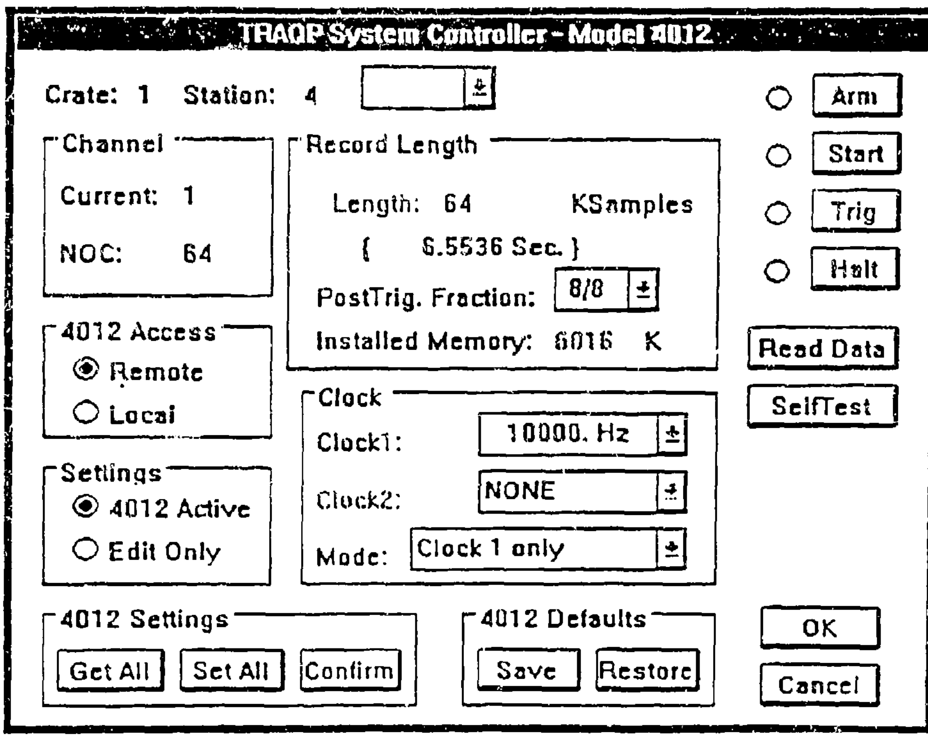


Figure 5.5.5
Impax System Controller Form

changed up to a maximum of 128 K samples. Click on the "Length" line of this group and specify the desired value. The total data recording time is specified immediately below this line. The time is shown in seconds. This time is directly related to the size of the record length above and the sample rate specified in the "Clock" group. The higher the record length or clock rate, also called the sample rate, the smaller the recording time will be. The system sample rate is specified in the "Clock" group at the "Clock1" line. According to the standard, SAE-J211, the sample rate at which channel data can be collected has to be at least eight times the characteristic frequency "Fh" for a channel frequency class of 1000. To comply with these requirements, the data acquisition system is set to sample at a rate of 10000 Hertz. Once all settings have been verified, use the "Save" option in the "4012 Defaults" group to set these parameters as the default values. It is important to mention that this form remains almost unchanged from test to test and that these window default values have been set to the parameters currently shown in figure 5.5.5. It is customary and recommended, however, to access this form every time a test will be run and check that the settings match those of the aforementioned figure. To exit this menu, click on the "OK" box on the lower right corner. The Impax main menu will appear back on the screen.

5.5.5) Zeroing and Balancing Channels

The next step in setting the data acquisition system for a test run involves zeroing and balancing transducer channels. The "Setup" option in the Impax main menu allows for this task. This setup operation consists of two phases, setting and scaling. Setting involves setting instruments gain and offset as required for the requested full scale. Scaling involves calibrating the data channel. In order to perform the setting phase, the signal must be fully defined, that is, transducer and DAS channel in use must be specified, requested full scale, etc. Refer to previous sections for information on how to define signals. Once the setting phase of the operation is completed successfully, scaling is carried out.

To run the setup operation, click on the "Setup" menu of Impax main menu. This will open a sub menu that permits automatic, single or group (crate of channels) zeroing and balancing. If the automatic option is chosen, all signals defined in the Impax signal directory will be setup. If single channel is the choice, the signal currently selected in the signal directory will be zeroed and balanced. Depending on the setup method, the process goes through different stages. All progress of the operation is displayed in the Log Window of Impax. If the operation ends successfully the setup window will close automatically and the Impax main menu will be displayed back on the screen. In this case the "Status" column in the signal directory should read "ready" for all signals that were successfully zeroed and balanced. See figure 5.5.1. If problems are encountered, error messages will be displayed on the screen and at the end of the operation a list of signals not correctly setup will be displayed. This list may be used in conjunction with the signal directory and single channel setup to correct the problems. Refer to section 5.5.9 for procedures to determine possible causes of failures in the zeroing and balancing operation and solutions to the problems. If automatic setup is used for all the signal and failure occurs for some channels, it is recommended that a single channel setup be run for each individual failed channel to verify that a problem still exist. If this is the case then the reader should refer to section 5.5.9.

Once all channels have been setup correctly, a checkout operation is always recommended. In Impax, checkout provides a means of monitoring or measuring DC levels on a single channel. Choose the "Checkout" menu of Impax main menu and a variety of options will be displayed. Choose the "Measure A/D Converter Output" option. This action will initiate a display of channel readings in the Log Window of the Impax main menu. The Log Window is periodically updated with the requested measurement. Three values are shown for each measurement: average, peak to peak and RMS. The average value should be very close to zero for a well zeroed and balanced transducer. Measurements are stopped by pressing the "Abort" button in the "Process Control" dialog box.

In addition to the checkout option, Impax offers a window with a summary of the scaling information obtained during the setup process. Click on the "Directory" menu in the Impax main menu. In this menu choose the "Scaling" option and a window similar to figure 5.5.6 below, will be displayed. In this window, the column labeled "Sig" displays the channel reference number defined in the signal directory. Columns labeled "Sens0", "Sens1", "Sens2" and "Sens3" include sensitivity coefficients which are used along with the transducer full scale to calculate the transducer sensitivity value. The remaining

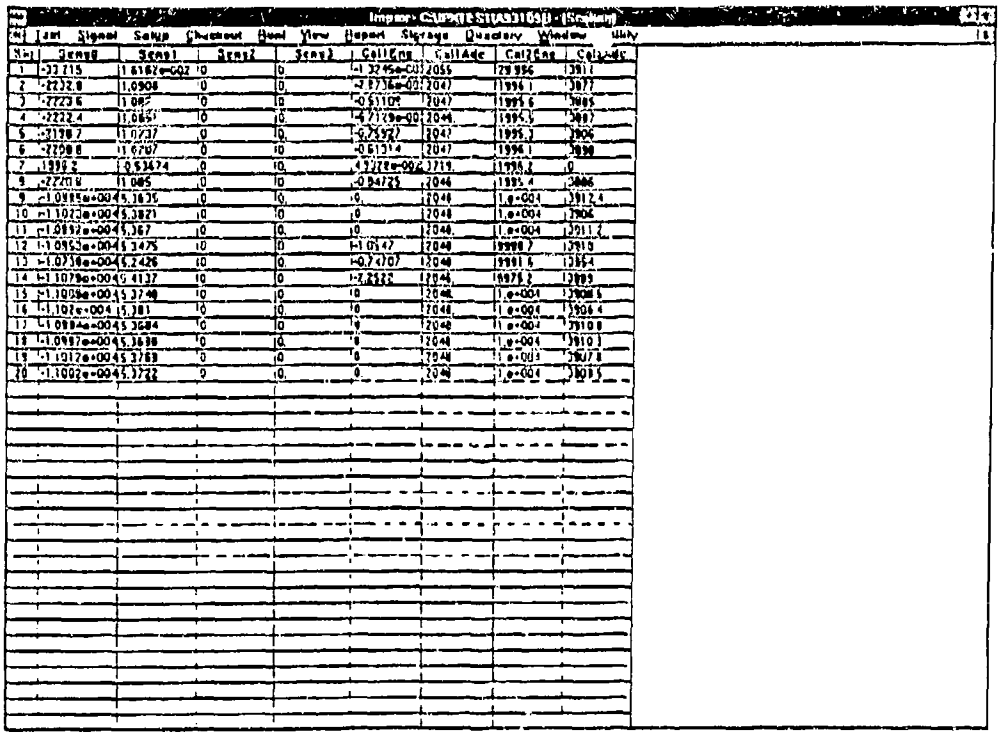


Figure 5.5.6
Impax Scaling Information Form

columns contain scaling points calculated from the measured data. These are labeled "Cal1" and "Cal2" and are given in both, engineering and DAS converter units. Column labeled "Cal2Eng" includes the transducer full scale. For a well zeroed and balanced transducer this value should closely match the maximum full scale specified in the

transducer description form (figure 5.5.3). If problems are encountered during the set up operation, the information displayed in this scaling window will not match values specified on the transducer's description form. Section 5.5.9 covers some trouble shooting procedures.

5.5.6) Running Impax

At this point the process of setting up Impax to perform a test is finished. If all of the steps in the previous parts of this section were followed and completed without any problem the system should be ready to monitor and collect data from the transducers. This process of running Impax is described next.

In the Impax main menu, click on the "Run" option to open the Data Acquisition Control dialog box. This box allows user control of the data acquisition system control modes. Upon opening the box, an "Idle" message will be displayed to state the status of the data acquisition system. This message indicates that data acquisition is not active. The Data Acquisition Control dialog box also contains four different options: "Start Acquisition", "Generate Trigger", "Abort Acquisition" and "Cancel." Select the "Start Acquisition" option to begin data collection. Initially Impax will check that all signals have been setup, zeroed and balanced, correctly. If any signal has an incorrect status a window will open listing the failed signals. Normally it is advisable to cancel the running process and rerun a setup operation to correctly prepare the signals, however, the operator can choose to override the warning message and continue with starting the acquisition process. If all signals are correctly setup, Impax will prompt the user with a confirmation of the start command before the Data Acquisition System is started. Select the "OK" option to confirm starting the system. This action will set the DAS in pre-trigger mode which means that data is being collected and stored in the DAS memory module. If the DAS is in pre-trigger mode the Data Acquisition Control dialog box status will change from "Idle" to "Digitizing." In this mode the system will keep collecting and storing data until a trigger signal is generated. The DAS can be triggered manually using the "Generate Trigger" option or it can be triggered remotely by an external signal. At this lab the DAS is triggered with a remote signal. The signal comes from the propulsion system control panel when the "Energize/Fire" switch is pressed (refer to section 3.2). If remote triggering is to be attempted the system is left in the "Digitizing" status. When the remote signal is received, the system will automatically issue what is called a Stop Trigger to all DAS recorders. This action will set the DAS in post-trigger mode and a "Triggered" status will be displayed in the Data Acquisition Control dialog box. When the post trigger recording is finished, at a time determined by the post trigger record length (see figure 5.5.5), recording will be halted. The dialog box status will go back to "Idle." If manual trigger is to be used, select the "Generate Trigger" option. A confirmation request will be made by the system. Upon positive confirmation the system will issue a Stop Trigger. Subsequently, the same routine is followed as if the system would have been triggered remotely. After data acquisition has terminated, the "Run" option can be exited by selecting the "Cancel" item in the Data Acquisition Control dialog box. At any time the data acquisition process can be aborted by using the "Abort Acquisition" option.

Refer to section 5.7 for information on how Impax is run in conjunction with other control systems when performing a run.

This summarizes the run procedures using Impax. The reader is referred to the "Impax Refer nce Manual" for more detailed information.

5.5.7) Data Storage

Up to this point all the options and menus of Impax that have been discussed dealt with preparing the data acquisition system to perform a test run. This section and section 5.5.8 review features of Impax that involve post test procedures. Although they are not needed to perform the test, they are indispensable in the post test storage, reduction and analysis of the collected data. Specifically, this section deals with the "Storage" option of Impax.

Impax storage functions are responsible for transferring data from the Data Acquisition System memory module to the computer's hard drive to create a permanent record of the measurements. This procedure is usually carried out immediately after the test run is completed. To access the "Storage" menu, click on the item in the Impax main menu. A small window will display different options available from this menu. These include: "Control", "Store", "Store Instrumentation Setup", "Store Region of Interest" and "Archive Data Record." The "Control" option allows the user to select which channels to store, the extent of the data to be saved, and the information that is to be included in the output data file header. Although the reference manuals for Impax suggest that the "Control" option only needs to be used if changes in the storage mode are needed, the user is advised to verify the control parameters before the "Store" option is used. Figure 5.5.7 shows the window that is displayed by Impax when the "Control" item is selected. This window is divided into four groups. At the group labeled "Signals", the user can enable or disable signals. Enabling a signal allows the system to store it. For all signals to be stored, verify that a check mark is displayed at the "Act" column. The status at this column can be switched by double clicking on the checkbox cell. In figure 5.5.7 all signals have been enabled for storage. In the "Data" group specify the directory where the collected data will be stored. It is customary to store the complete record length for each signal, therefore, the "Complete Record" box should be selected. The record length, in the "Data" group, corresponds to the one specified in the system controller form shown in figure 5.5.5. In the "Position of Time Zero" group verify that the "Time Zero Position" box is set to the first sample. This will allow the location of time zero in the collected data to correspond to the time when the Data Acquisition System was triggered. The group label "Contents" allows the user to specify what information will go into the header of the output data file that is created when the storage process is carried out. Figure 5.5.7 shows what is usually included in this header. Verify that these same options are selected in this group. Once all previously described items have been accordingly changed and/or verified, proceed to save and close the storage "Control" menu by clicking the "OK" box.

The next step involves performing the storing process itself. The system allows for automatic data storage when the "Store" item is used. Upon clicking on this item the system will store the data for each channel specified in the "Control" option above. As the storing process is carried out, the system will display information regarding the status of the process in the Log Window of the Impax main menu. The system will automatically close the "Storage" menu when all selected signals have been stored. The user can verify

that all signals were stored in the specified directory by using the File Manager in Windows.

The other options of the "Storage" menu are also important, however, they are not described in this section because their use is optional. The reader is referred to the "Impax Reference Manual" for information in these options.

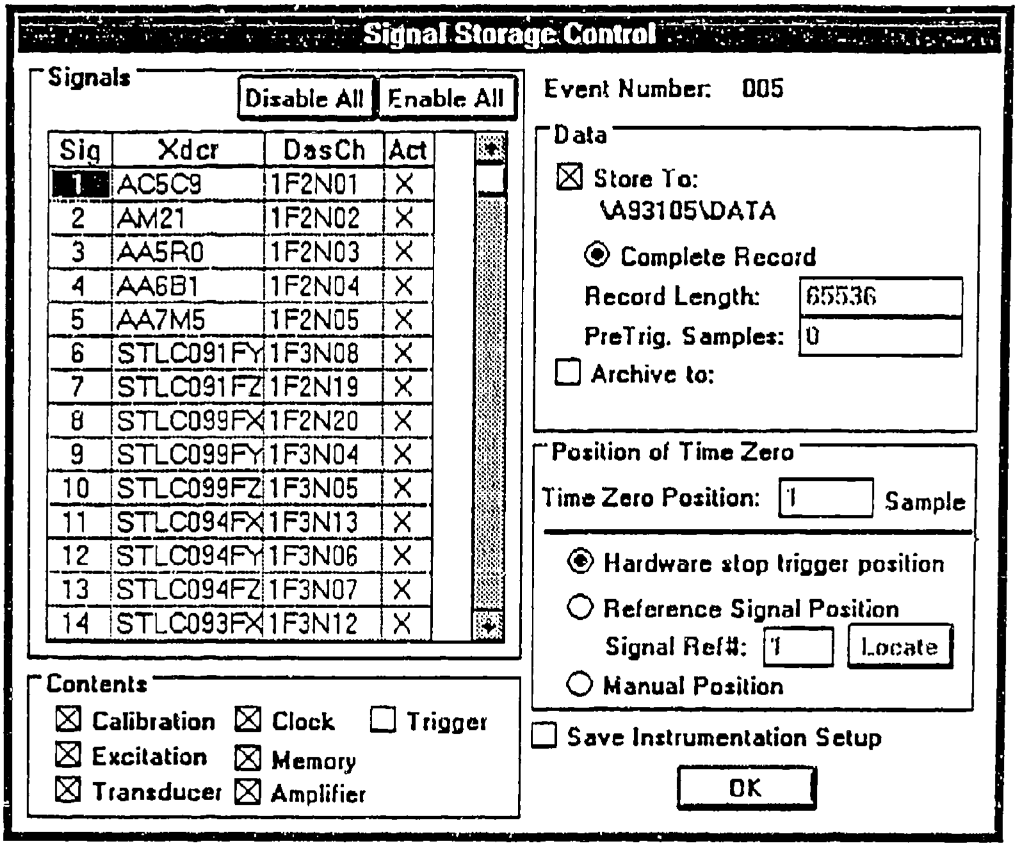


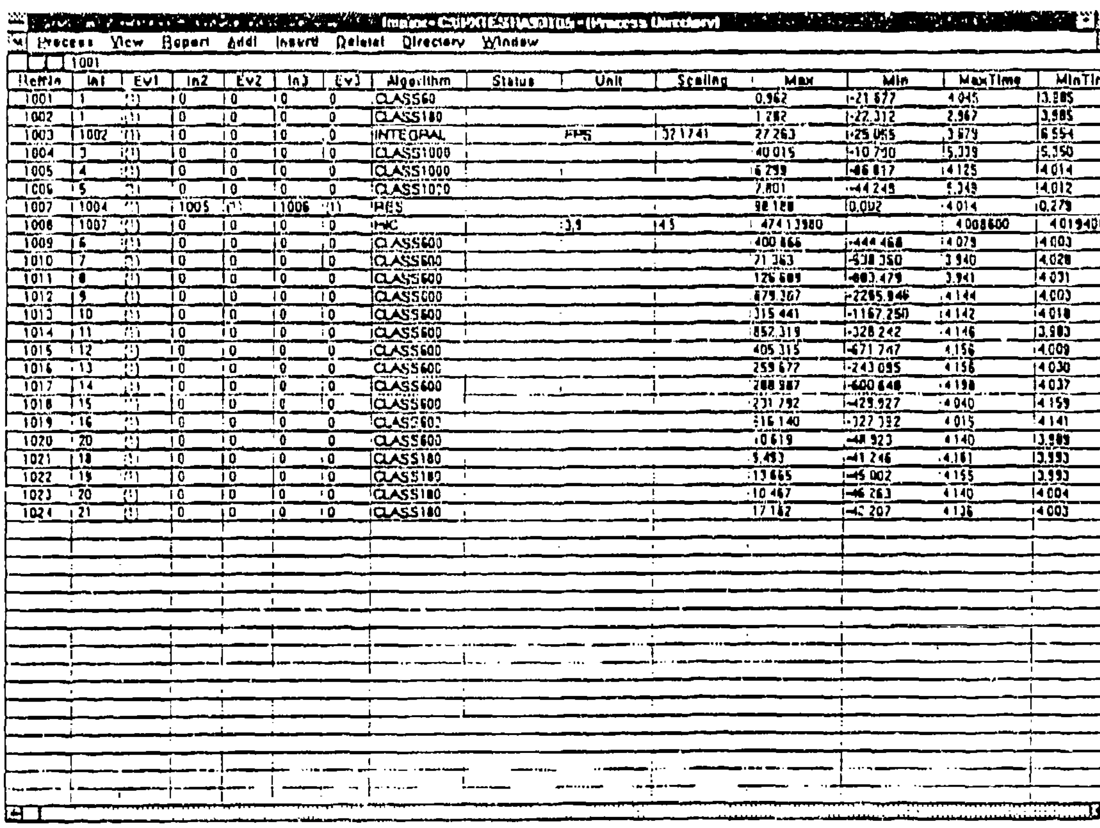
Figure 5.5.7
Impax Signal Store Control

5.5.8) Signal Processing

It was previously mentioned that signals collected from this data acquisition system are run through conditioning amplifiers where the filters are preset to a frequency of 2900 Hertz. It was also mentioned that at this filter frequency the collected data remains unfiltered. The data needs to be filtered at required frequency levels to be in compliance with the standards set in SAE-J211. The Impax package includes an option that allows for this filtering process of recorded raw data. In addition, this option provides other features that are very useful in the interpretation and analysis of test data after a run has been completed. This section deals with how to use this option of Impax and discusses some of the features it includes.

In Impax, access the "Process Signal Directory" option by clicking on the "Signal" option of the main menu bar. Upon clicking on this option a window similar to the one shown in figure 5.5.8 will be displayed. This is a list of all signals that are to be processed.

In this window each processed signal is assigned a reference number that is listed in the first column of the Process Directory as "RefNo." The input source is specified as another signal reference ID in the second column, "Input1." This input source can be any valid reference number from the Impax Signal Directory, if raw data is to be processed, or from the Process Signal directory below, if preprocessed data is to be used in another signal reduction process. The third column of the Process Signal directory contains what is called the event number, Event1. It is the event number of the "Input1" source signal. Every time a signal is stored it is assigned an event number, the first event being "1." The most recent event is processed regardless of the number of events stored or previously processed if "Event1" is assigned the value of "-1." Columns 4 through 7 provide for additional source signal identifiers used with algorithms requiring multiple inputs. The eighth column defines the mathematical operation or algorithm to be performed on the input source signal(s). To access the different algorithms available, double click on the "Algorithm" box of each row and a pull-down pick list will be displayed. The different algorithms include: ADD, SUB, RESULTANT, CLASS1000, CLASS600, CLASS100, CLASS60, INTEGRATE,


Process View Report Add! Insert! Delete! Directory Window

1001

RefNo	In1	Ev1	In2	Ev2	In3	Ev3	Algorithm	Status	Unit	Scaling	Max	Min	MaxTime	MinTime
1001	1	(1)	0	0	0	0	CLASS60				0.962	-21.677	4.045	13.805
1002	1	(1)	0	0	0	0	CLASS180				1.782	-22.312	2.967	3.985
1003	1002	(1)	0	0	0	0	INTEGRAL		FPS	321741	27.263	-25.065	3.679	6.554
1004	3	(1)	0	0	0	0	CLASS1000				40.015	-10.790	5.339	5.350
1005	4	(1)	0	0	0	0	CLASS1000				6.299	-46.817	4.125	4.014
1006	5	(1)	0	0	0	0	CLASS1000				7.801	-44.245	5.349	4.012
1007	1004	(1)	1005	(1)	1006	(1)	RES				98.188	0.002	4.014	0.279
1008	1007	(1)	0	0	0	0	HIC		3.9	45	474.13980		4.008600	4.019400
1009	6	(1)	0	0	0	0	CLASS600				400.866	-444.468	4.079	4.003
1010	7	(1)	0	0	0	0	CLASS600				71.363	-538.350	3.940	4.028
1011	8	(1)	0	0	0	0	CLASS600				126.609	-803.479	3.941	4.031
1012	9	(1)	0	0	0	0	CLASS600				879.367	-2285.946	4.144	4.003
1013	10	(1)	0	0	0	0	CLASS600				315.441	-1167.250	4.142	4.018
1014	11	(1)	0	0	0	0	CLASS600				852.319	-328.242	4.146	3.983
1015	12	(1)	0	0	0	0	CLASS600				405.315	-671.747	4.156	4.009
1016	13	(1)	0	0	0	0	CLASS600				259.677	-243.095	4.156	4.030
1017	14	(1)	0	0	0	0	CLASS600				288.987	-600.648	4.198	4.037
1018	15	(1)	0	0	0	0	CLASS600				231.792	-429.927	4.040	4.159
1019	16	(1)	0	0	0	0	CLASS600				16.140	-327.392	4.015	4.141
1020	20	(1)	0	0	0	0	CLASS600				10.619	-48.923	4.140	3.989
1021	18	(1)	0	0	0	0	CLASS180				5.493	-41.246	4.161	3.993
1022	19	(1)	0	0	0	0	CLASS180				13.665	-45.002	4.155	3.993
1023	20	(1)	0	0	0	0	CLASS180				10.467	-46.263	4.140	4.004
1024	21	(1)	0	0	0	0	CLASS180				17.182	-42.207	4.136	4.003

Figure 5.5.8
Impax Process Signal Directory

DERIVATIVE and HIC. Refer to the "Impax Reference Manual" for information on these algorithms. The "CLASSxxxx" option of these algorithms allows the user to filter

data in accordance with different channel frequency classes. To estimate the Head Injury Criteria of a specific anthropomorphic test dummy (ATD) the option "HIC" is offered. This option requires its input to be the resultant of a triaxial accelerometer. To estimate the resultant use the "RESULTANT" algorithm which requires the input from three different sources. Rows 1007 and 1008 of figure 5.5.8 show an example of this. Selection of these algorithms defines the process that will be performed on the input signal.

The Process Signal Directory offers different options in its menu. Of these options the "Process" item is the most important to analyze test data. In this report this option is the only one to be discussed. The other options are discussed in the "Impax Reference Manual." The "Process" option performs analysis on a single or all signals in the Process Directory. Click on this option of the menu bar of this directory and choose either the "Selected Signal" or the "All Signals" option to carry out the desired operation. Upon selection, the process is started and messages are displayed in the Log Window of Impax indicating the nature of the process and its results. Once the process is completed the new processed signal or data is stored in the "data" sub directory of the current Impax directory, (C:\IPXTEST\Test number\DATA). At the Log Window the file names assigned to each data file are displayed. Files are usually referred to as "1001clas.001", where the first digits correspond to the "RefNo" of the signal, the "clas" label refers to the algorithm used in the process and the last three digits indicate the Impax test number for which the signals where processed. Some of this processed signal data is used later to evaluate the results of the test run.

Once all desired signals are processed the Process directory window can be closed and the Impax main menu will be displayed on the screen.

In addition to this menu, Impax includes another menu called "Utility" that should probably be treated in a separate section, however due to the nature of its application it is briefly reviewed in this section. Files created or manipulated in Impax are formatted under a particular configuration designed by the Impax creators, DSP Technology Inc. This file format is called DSP format and can only be used by Impax routines. The Impax "Utility" menu allows the user to convert a data file from DSP format to ASCII and vice versa.

Some of the data that has been processed with the "Process Signal Option" described above is later used to evaluate the sled deceleration pulse using program XL31 described in section 5.9.2. This processed data needs to be in an ASCII format in order to be used by XL31. Click on the "Utility" menu of Impax main menu to access the "Convert Data" option. Under this option, choices to convert data from DSP to ASCII and ASCII to DSP formats are presented. The system will display a window where the name of the source file to be converted is requested. This file can be found in the file directory indicated in the "Data" group of the "Control" option in the "Storage" menu (C:\IPXTEST\Test number\DATA) shown in figure 5.5.7. Subsequently, after the source file name is specified, a similar window is displayed requiring the name of the destination file that will contain the converted data. This file is usually stored under the directory C:\DBASEFIL. The process of converting the data starts immediately after the destination file name is entered. At the Impax Log Window the status of the process is displayed. This conversion process needs to be repeated for each signal.

As for the previous parts of this section, if problems are encountered while processing signals, the reader is referred to the next section for trouble shooting procedures.

5.5.9) Trouble Shooting

In this section recommendations for solving some of the problems that may be encountered when running Impax are made. Impax is designed to provide the user with warning messages if abnormal operation of the system occurs. These messages are helpful when trying to determine what causes the abnormal condition, however, they are not very explicit. Most of the recommendations made here are based on past problems that the lab personnel have experienced when working with this system and software. They are aimed to help the reader to interpret warning messages provided by Impax. Although some of the probable causes presented here may some times appear obvious because of their simple nature, the reader should remember that under test conditions the operator finds him/herself dealing with many aspects of the test operation and he/she may inadvertently overlook what is causing the problem. The section is composed of a list of these problems, probable causes and solutions.

- **Problem:** Setup procedure can not be started due to high gain values in channel amplifiers.
  Probable Cause: Data Acquisition Unit may have been off when Impax was initiated.
  Solution: Check if all crates in DAU are "on." Verify that transducer cables are properly connected. Close and re open current test in Impax. Check channel amplifier setting before setup procedure is attempted again
- **Problem:** Setup operation failed because channel offset limits were exceeded.
  Probable Cause: The transducer in use may be due for calibration.
  Solution: Check calibration due date in log books. Inspect transducer connector at the blue box (figure 3.3.1). In particular verify that wires are well attached to connector pins.
- **Problem:** Setup operation failed because noise level exceeds limit.
  Probable Cause: Channel amplifier may be picking up noise from external sources.
  Solution: Check connection of transducer at blue box. Inspect transducer cable for proper condition. Verify integrity of the cable shield. Run transducer through a different channel, if problem disappears then possible damage in the umbilical cable may exist for that specific channel.
- **Problem:** System is unable to balance instrument.
  Probable Cause: Transducer may be due for calibration. Transducer may be permanently damaged. Bad connection at transducer plug may exist or transducer cable may be broken.
  Solution: Run instrument on a different channel. Check resistance across arms of instrument internal bridge. Bridge arms may be broken if no resistance is read across them. Instrument may need to be fixed. If transducer in use is a strain gage check resistance of it. Verify that the actual gage resistance is within one Ohm of the specified gage resistance value.

- **Problem:** Channel amplifier settings display high gain, voltage and filter values.
  Probable Cause: Data Acquisition Unit was off when Impax was started.
  Solution: Turn DAU on. Close Impax window and re open it.
- **Problem:** Application error occurs when trying to access the "Controller" option under the "Signal" menu.
  Probable Cause: Data Acquisition Unit was off when starting Impax.
  Solution: Turn DAU on. In this case the system will force rebooting of the computer. Start Impax as usual after rebooting the system.
- **Problem:** No data stored when "Store" option of Impax was used.
  Probable Cause: No record length was specified in the signal controller form (figure 5.5.5). No directory was specified to store data.
  Solution: Check system controller form under the "Controller" item of the "Signal" menu in Impax. Verify that an appropriate length has been specified in the "Record Length" group. Check the "Data" group in the Impax "Control" option of the "Storage" menu (figure 5.5.7). Verify that a valid directory has been specified to store the data. Confirm that the "Store to" box has been selected and that the record length specified in system controller form is displayed.
- **Problem:** Impact event portion of signals not included in output data file.
  Probable Cause: Not enough record length was specified to store data. This may happen if system sample rate is increased without shorten length of the records. Refer to figure 5.5.5.
  Solution: Change record length and sample rate in the signal controller (figure 5.5.5) to allow enough recording time. Caution: System sample rate should be kept at 10000 Hertz to satisfy standards.
- **Problem:** Attempt to open "Signal Process Directory" under the "Signal" menu fails.
  Probable Cause: DAU may be off.
  Solution: Turn DAU on. Close and re open Impax. Open "Signal Process Directory"
- **Problem:** High readings are displayed when running a "Checkout" on a specific channel.
  Probable Cause: The channel in used was not zeroed and balanced before performing the checkout operation. Transducer may be damaged or due for calibration.
  Solution: Zero and balance transducer and run checkout operation again.
- **Problem:** Scaling information does not match specified instrument settings (sensitivity, full scale, etc.).
  Probable Cause: Transducer may be damage or due for calibration. Transducer may need to be zeroed and balanced.
  Solution: Re zero and balance transducer. Check transducer for external damages and condition of cable. Verify that transducer is not due for calibration.

5.6) Pre Test Inspection

Up to now, a full description of procedures for preparing the sled system for a test run has been presented. The last step of this operation, before launching the sled, consists of performing what is called a "lab-walk-around". This is a final inspection on all items and systems involved in the test run. In particular this procedure concentrates on pre launch conditions of the sled and payload, track and cables, restraining system, data acquisition system, and lab test condition. In spite of the fact that previous verifications may have already been made when the lab's different systems were being prepared for the test, it is imperative that this last inspection is carried out with much caution. Errors in system settings should be detected during the inspection to eliminate any unforeseen condition that may cause damage to the sled system. The present section deals with this pre test inspection.

The different aspects of the inspection are covered in thirteen sequential steps as shown in figure 5.6.1 below. This particular sequence does not need to be followed as presented here, however, it is very important that all the steps of the inspection are covered.

The inspection procedure starts at the end of the sled track at the impact area. For step ① verify that the sled tow cables are properly accommodated in the grooves of the cable pulleys. The pulleys are shown in figure 3.2.2. While walking from step ① to step ②, inspect the condition of the sled track and tow cables. Check that the cables are laid as far apart from each other as the cable wooden supports allow. Make sure that the cables are lying on top of the supports all the way along the track length. Verify that the rails have been cleaned and oiled and that the adjacent floor area is clear of any object (tools, bolts, etc.). At step ② inspect the test article-sled arrangement for loose parts. Confirm that the test article is well secured. If ATDs are included as part of the arrangement, verify that their restraining systems are locked and properly tightened. Check transducer cables to make sure they have been taped down. Check the cable's connections at the "blue box". Look for tools and other parts that operators inadvertently may have left on the sled or surrounding area. Inspect the sled shoe pads for proper condition. Check the upper probe's alignment using the steel cross bar as described in section 5.2.5. Use your hands to verify that probe head rollers rotate freely. The sled tow rope should be disconnected from the sled and tow winch and should be kept in its storage bucket away from the sled. Verify that the safety pin (figure 3.2.1) that secures the sled in position is engaged. The sled system is provided with a warning device that connects to this safety pin. When the safety pin is disengaged, leaving the sled free to be launched, this device emits a loud repetitive beep. A green light on the device indicates that the safety pin is engaged. Next, move on to step ③ to check the cine lighting system switch board. The by-pass switches on this board need to be in the enable position. Check also that the impact area back drop has been pulled down. At step ④ reset the velocity trap control box and confirm that the digital indicator reads 0.000 milliseconds. At the left of the reset bottom a yellow light will turn on when the box is reset. Steps ⑤ and ⑥ deal with inspection of the sled restraining

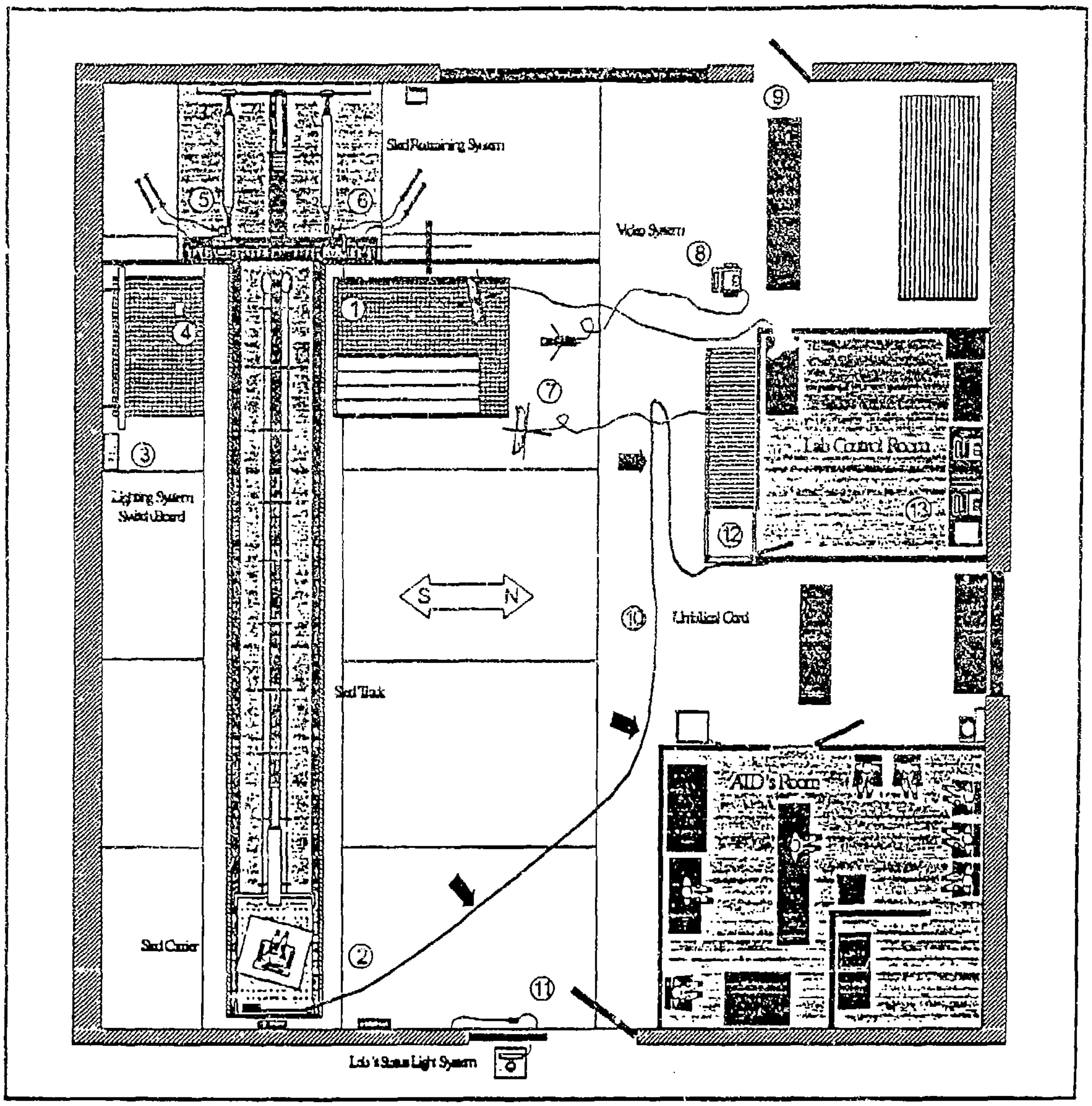


Figure 5.6.1
Impact Dynamics Lab Pre-Test Inspection

system. At step ⑤ verify that the clamp cage and its safety valve are fully closed. At step ⑥ make sure that the roller cage has been pressurized to its second position. Refer to section 5.3.3. This cage's safety valve must be fully closed as well. Verify that all of the cages hydraulic pump handles are in the upright position indicating a pressurized condition. At position ⑥ also verify the length of the straps as described in section 5.3.3. Change the strap arrangement if the strap lengths do not match those required to provide the proper test conditions. The threaded rod that attaches to the clamp and roller cages should be well secured. See figures 3.3.3 and 5.3.2. Verify that the wooden step blocks have been taken out and that no other tools or items have been left in the restraining system area. It is customary to apply a graphite based lubricant paste on the restraining

system latera cross member at the area where the shoe on the upper probe head contacts this member. This area is called the contact zone. This is done to record the first point of contact between the probe and the cross member. Refer to section 5.8. Verify that enough paste has been applied to completely cover the contact zone. Also make sure that no traces from previous tests are present. If needed, spray the restraining system straps with synthetic oil. Next move to step ⑦ and turn on the floor level spot lights. At step ⑧ check the settings on the video camera system. Specifically check the system recording speed and imagers in use. Also make sure a video tape is loaded in the unit to record the event. At step ⑨ verify that the lab's back door is closed and locked. Step ⑩ involves moving the umbilical cord away from the track as indicated in figure 5.6.1 above. Next, in step eleven, the lab's status light needs to be switched to red. The red light indicates that an extreme hazard condition exists within the lab. The lab's front door is locked from inside with a dead bolt so that no person has access to the lab during the test run. At this point all non lab personnel should be located in the ATD's Room or the Lab Control Room. Verify that the ATD's Room door is closed. Step twelve involves a visual overall inspection of the lab area for any abnormal condition. Close the door for the lab's control room. Step thirteen, the last step of the inspection, involves checking on the data acquisition system with Impax. Check with the lab personnel when the transducer's setup operation (zeroing and balancing) was last carried out and proceed to perform it again if needed. Refer to section 5.5. In the Impax main menu, in the Signal Directory, look at the column labeled "Status" and verify that all signal transducers show a "Ready" condition, see figure 5.5.1. Go into the Impax Scaling Information Form, figure 5.5.6, and check the transducer's calibration data. Refer to section 5.5.5. Although a tedious process, it is also recommended to check all of the channel amplifier settings as described in section 5.5.3. In addition, check on the settings for the Data Acquisition System Controller, described in section 5.5.4. If any of the channels present unusual settings, run a checkout operation on the specific transducer and verify its reading. Refer to section 5.5.9 for trouble shooting procedures if problems are encountered.

Checking on the condition of the data acquisition system is the last step of the pre test inspection. Make sure that all of the lab personnel are in their required positions and ready. Section 5.7 describes the test running operation.

5.7) Running the Test

Running the sled system is a sequential procedure where the steps can not be omitted and need to be followed as described. This is the most critical part of the test operation, therefore, extreme attention should be given to all aspects of the sequence. Should an abnormal condition in any of the systems occur during the pre launch stage, the process should be aborted and corrective measures taken. Verify again that all systems are functioning properly and perform this procedure from the beginning.

There are three components involved in controlling the running process. These three components are two 486 IBM compatible computers, labeled A and B, and the propulsion system control panel. Computer A is used to run the Impax software. Computer B is used to run a program called Crashv that controls the video camera, the cine lighting system, and sends a trigger signal to the data acquisition system. These three components are interconnected and function as a whole.

To initiate the running procedure all sled systems should be ready to perform the test. This is only done once the pre-test inspection is finished. First, start by checking on the propulsion system control panel settings. Refer to figure 3.2.3. The main power switch and light of the panel should be on. All other lights in the panel should be off. Confirm that the "Vent/Pressurize" switch is in the neutral position and verify that the pressure reading, shown in the digital meter next to the control panel, matches the required pressure value for the test. Use the "Vent/Pressurize" switch if any pressure level adjustments need to be made. On the fire box, the small box next to the control panel, the "Enable/Disable" switch needs to be in the disable position. The control panel is now ready to run the launching sequence. On computer A, the Impax main menu should be displayed. Access the "Run" option and perform an Impax running procedure as described in section 5.5.6. It is customary to remotely trigger the data acquisition system. For remote triggering, the Data Acquisition Control dialog box should display "Digitizing" as shown in figure 5.7.1. Impax is then ready to receive the trigger signal. Next, on computer B, run program Crashv by typing the command: Crashv at the "C:\" prompt. First, the program will ask for the total run time in seconds for the test. Seven seconds is usually an adequate amount of time. Next the program asks for the time delay in seconds for the pressure valve. Enter the required value for the test. Refer to section 4.5 for information on delay time estimation. The program then issues the message " Hit "RETURN" to start lighting, DSP, and camera". Do not hit the "RETURN" key yet. Move on to the propulsion system control panel and activate "ARM CONTROLS" and "ARM SYSTEM" switches. Their lights will come on. Next at the fire box move the "Enable/Disable" switch to the enable position. When doing so, on computer A, verify that the Data Acquisition Control dialog box still displays "Digitizing". If it shows "Triggered" abort the launch sequence and re run a setup operation with Impax. The launch process should be started from the beginning if this happens. At this point, take a moment to check the status of all three systems and proceed to launch the sled. On computer B hit the RETURN" key. This action will turn on the cine lighting syst[illegible]ger the video camera system and issue the remote signal that triggers the data ac[illegible]stem. The program will display the message "Ready to FIRE". Immediat[illegible]ove the "SAFETY" switch on the propulsion system control panel to the on pos[illegible] light on this switch will come on and a loud repetitive beep sound will be heard ind[illegible]at the safety pin is disengaged. Subsequently push the "Energize/Fire" bottom in the fire box. This action will launch the sled. On computer A the dialog box will read "Triggered" and on computer B the message "Crash Sled Launch initiated" will be displayed. A normal test run lasts approximately 2 to 3 seconds. Wait a few seconds after the event is over and then proceed to move the switches "SAFETY", "ARM SYSTEM" and "ARM CONTROLS" to their off positions. This is done when the dialog box on computer A reads "Idle" and the message "Crash Sled sequence complete" is displayed on computer B. Move "Enable/Disable" switch in the fire box to the "disable" position. The program Crashv automatically turns the cine lighting system off and stops the video camera system. This terminates the launching sequence. Figure 5.7.2 below shows steps to follow when the program Crashv is run.

Follow the procedures described in sections 5.5.7 and 5.5.8 to perform data storage and signal processing. This is done immediately after the test is finished.

Lab personnel should perform a quick inspection of the lab area and verify that a safe condition exits before any non lab personnel are allowed to inspect the test article. A

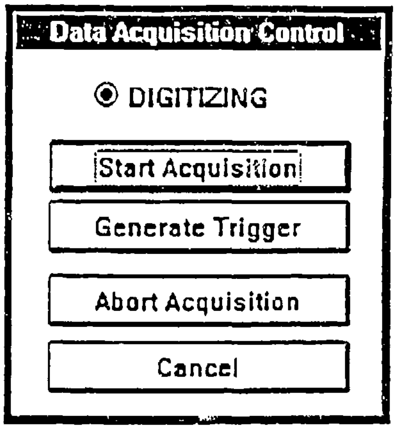


Figure 5.7.1
Data Acquisition Control Dialog Box

```
C:\> crashv                                            ⇦ Program starts

Enter total run time for crash in seconds              ⇦ Enter total time

7

Input time delay for pressure valve in seconds         ⇦ Enter time delay

1.85

Hit 'RETURN' to start lighting, DSP, and camera        ⇦ Start systems


Ready to FIRE                                          ⇦ Wait for trigger

Crash Sled launch initiated                            ⇦ Trigger is received and sled is launched

Crash Sled sequence complete                           ⇦ Program stops


C:\>
```

Figure 5.7.2
Program Crashv Sequence

sled system inspection follows after the test is completed. This inspection is described in section 5.8. below. Unlock the lab's main door and switch the lab status light to yellow.

This warns people entering the lab to proceed with caution since a pressurized condition still exists in the propulsion system tanks.

5.8) Post Test Inspection

At this point the test run has been completed and the sled rests at the impact area. A post test inspection of the sled system always follows a run. Some of the observations made during this inspection are recorded in the log books. This information is later used for further development of deceleration pulses. In this section a brief description of this procedure is presented.

As previously mentioned, at impact, the sled deforms the straps in the restraining system until it comes to a rest. During impact the sled travels a certain distance which is designated as the stroke. The post test inspection starts with measuring the total value of the stroke. Using a measuring tape measure the distance between the strap line before impact and the front of the probe head as shown in figure 5.8.1. This distance is the total sled stroke. The stroke is recorded in the Test Documentation Form (figure 5.1.1) in the Post Event section. Next, check the position of the straps in the roller cage. Refer to figures 3.3.2 and 3.3.3. Specifically look for the location of the strap ends with respect to the rollers in the cage. Usually the location of the strap ends can provide a quick way of predicting how the deceleration pulse shape is going to look before the test data is processed. If the strap ends are pulled completely through the roller cage, making the safety strap the only strap left in the cage, it will be very likely that the deceleration pulse will have a "plateau" in the back side. On the contrary, if all strap ends are still very close to the idle roller when the sled comes to a rest, the back side of the pulse is very likely to have a steep slope. Relatively well proportioned deceleration pulses are usually obtained when the strap ends stop close to the pressure roller. Enter the location of the strap ends in the Test Documentation Form at the Test Description section. It is advisable to remove the straps from the restraining system after this step is completed. Upon removing straps visually inspect the roller and clamp cages for any damage. The next step in the inspection involves estimating the impact velocity of the sled. On the control box of the velocity trap check the reading displayed. This reading is the time that it took the velocity trap fin to go across the sensor. Refer to section 5.4.1. The lapsed time is given in milliseconds and the width of the fin is one inch, therefore the sled impact velocity, in feet per seconds, can be easily determined by the following equation:

$$\text{Impact Vel.} = \frac{83.33}{\text{Lapsed Time}} \quad \text{(ft/sec)} \qquad (5.8.1)$$

Enter the impact velocity in the Post Event section of the Test Documentation Form. Next in the inspection, check the probe's condition. Using the tow rope and winch pull the sled back until the probe head is a couple feet away from the lateral cross member of the restraining system. Slide the alignment bar, described in section 5.2.5, under the upper probe head. This bar provides support to the probe while the sled sits at this position. At the center of the restraining system lateral cross member, in the contact zone, look for traces left in the graphite paste. The contact zone is the area of the lateral cross member that is contacted by the probe head during impact. See figure 5.8.1. These traces can indicate if a re alignment of the probe is needed. A vertical alignment may be required

if the traces start close to the edge of the lateral cross member. Probe head rotation, shown in figure 5.2.4, may have also occurred if traces only show on the left side of the contact zone. These traces, although a good means of checking probe alignment, are used as a secondary check and should not supersede the probe alignment check procedure described in section 5.2.5. The general condition of the rest of the probe should

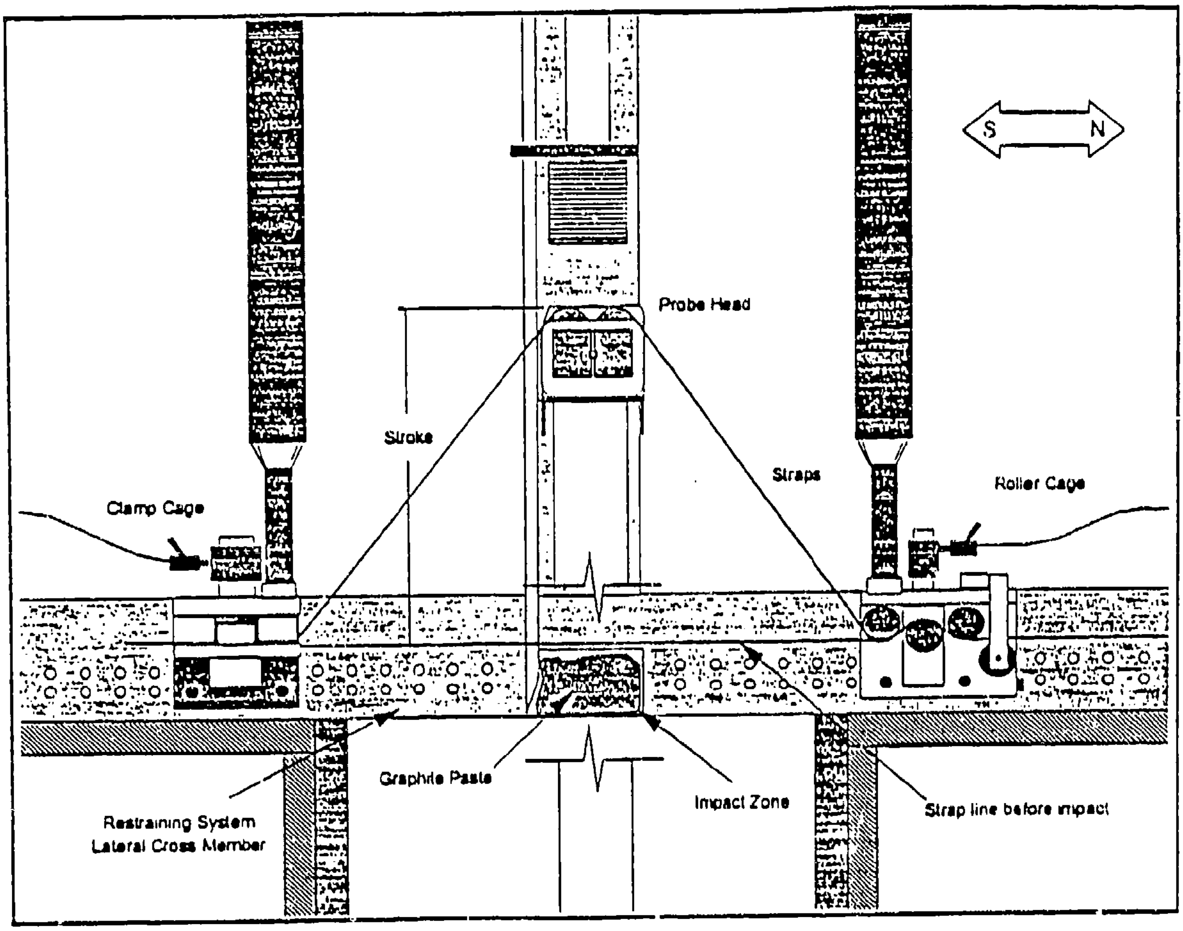


Figure 5.8.1
Post Test Inspection

also be inspected.

As a last step in the inspection, check the condition of the sled and test article. Inspect the test article and fixtures for any possible damage. Check also the condition of the anthropomorphic test dummies. It is important that no items on the sled are touched until the customer or owner of the test article authorizes it. Once the test article, dummies and test fixtures are removed from the sled template, check the template surface for damage.

Observations made during this inspection regarding stroke, straps position and impact velocity, are very useful in refining the deceleration pulse for the next test run. This information when used in conjunction with the results of the pulse evaluation provides a good tool to reshape pulses. The reader is referred to section 4.8 for information on pulse shape adjustments.

5.9) Processing Data

The last step in the test operation involves processing and reducing collected test data. Part of this procedure has already been explained in section 5.5 where Impax is presented. There exist standards and regulations that dictate how these procedures are to be carried out. In this section a brief review is given on what the standards stipulate regarding signal filtering and limiting test parameters. An overview of the program XL31 and the plotting package DSP Plot is also included.

5.9.1) Filtering According to SAE-J211

The Society of Automotive Engineers issued SAE-J211 to provide guidelines and recommendations for measurement techniques used in impact tests. The document covers all aspects of instrumentation set up. It is not the intent of this section to describe this standard but rather to indicate how Impax options work with these guidelines. The reader is advised to review J211 for detailed information.

In section 5.5.8 it was mentioned that Impax includes an option that allows for filtering of the data according to J211 specifications. In the "Process Signal Directory" different algorithms can be used to reduce test data. Of these algorithms, those called "CLASS60", CLASS100", etc. are available to perform the filtering operation.

J211 has classified different impact test measurements according to what they call the Channel Frequency Class or CFC. Table 1 of J211 shows a list of typical test measurements and their corresponding class number. The term channel refers to the data acquisition system channel being used to collect the data. The channel frequency number indicates that the frequency response of the channel lies within the limits specified in figure 1 of J211. Parameters Fh, Fn and Fl are designated to be the characteristic frequencies. In this figure little attenuation of the frequency response can be observed between frequencies Fl and Fh. This attenuation becomes more pronounced between Fh and Fn and presents a rapid decay beyond Fn. Frequency Fn is used as a reference to measure the attenuation of the frequency response. For example for a channel frequency class of 60, this figure indicates that at Fn = 100 Hertz, the limits are set to +0.5 dB and -4.0 dB.

Impax filtering algorithms are structured to provide dB points within the specified limits. For example, the algorithm "CLASS60" provides a -3.0 dB point at 100 Hertz. Similarly "CLASS1000" corresponds to a -3.0 dB point at 1650 Hertz and so on. These algorithms work as low pass 2 pole butterworth digital filter through which data is passed once in the forward direction and once in the reverse direction thereby achieving the attenuation of a 4 pole filter but without a phase delay. Refer to section 5.5.8 for information on performing filtering operations with Impax.

5.9.2) Evaluating the Sled Deceleration Pulse

Part of the requirements to validate a specific impact test is pertinent to the shape of the sled deceleration pulse. As was mentioned, the FAA has established these requirements and they can be found in FAR regulations parts 23, 25, 27 and 29. The deceleration pulse needs to be evaluated to determine if its shape comes close enough to

the specified pulse shape. A method to evaluate these pulses was developed by the Society of Automotive Engineers in document AS-8049. According to this method there are four parameters that need to be considered. These parameters are peak G level, rise time, velocity change during rise time, and total velocity change. These are specified as either minimum or maximum values. Section 4.1 gave a review of the evaluation method. A program, XL31, which executes a routine based on this procedure has been written by the lab personnel. It is standard procedure to use XL31 to evaluate deceleration pulses at this facility.

To run this program two data files are required. One contains sled accelerometer data that has been processed according to channel frequency class 60. The other file contains velocity data obtained from integrating sled accelerometer data that had already been processed to satisfy channel frequency class 180. To create these files, data collected from the sled accelerometers is reduced as described in section 5.5.8. First, the accelerometer data is processed using algorithm "CLASS60" to create the first data file (e.g. A93105.060).. Subsequently the unfiltered sled accelerometer data is processed using algorithm "CLASS180" and the output file is re processed using algorithm "INTEGRATE". The result is a file containing the velocity data (e.g. A93105.180). These files are usually stored under the directory: C:\DBASEFIL as specified in section 5.5.8.

From the Microsoft Windows program manager start XL31 by double clicking on the XL31 icon. On startup the program will ask for names of the two files described above. These are referenced as files CFC60 and CFC180. See figure 5.9.1 below. The

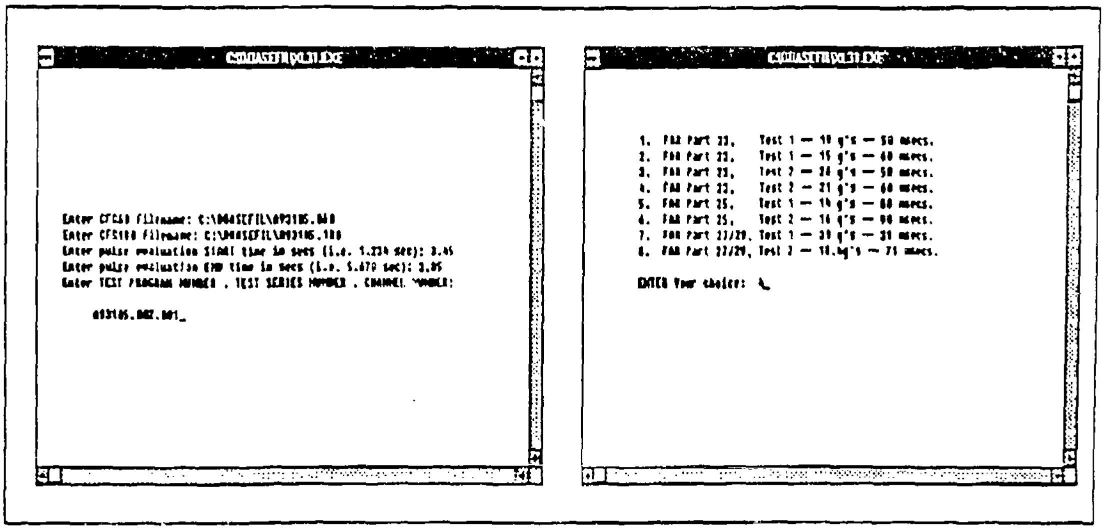


Figure 5.9.1
Program XL31 Sequence

program then requires the user to enter the start and end times that define the time period in which the pulse occurred. These time values can be determined from the plot of the deceleration pulse. Section 5.9.3 describes how to plot a pulse using DSP Plot. Subsequently a test number needs to be assigned. Upon entering all this information a new screen is displayed by the program. This screen shows a list of all of the different pulses that can be evaluated. Enter the appropriate choice. Figure 5.9.1 above shows the

sequence followed when executing the program. After the desired choice is entered, the program proceeds to execute the evaluation routine. The results of the evaluation are displayed on the screen and saved in the file "TESTREPT.DOC" under the directory C:\DBASEFIL. Figure 5.9.2 below gives an example of the evaluation results. Close XL31 window to exit the program.

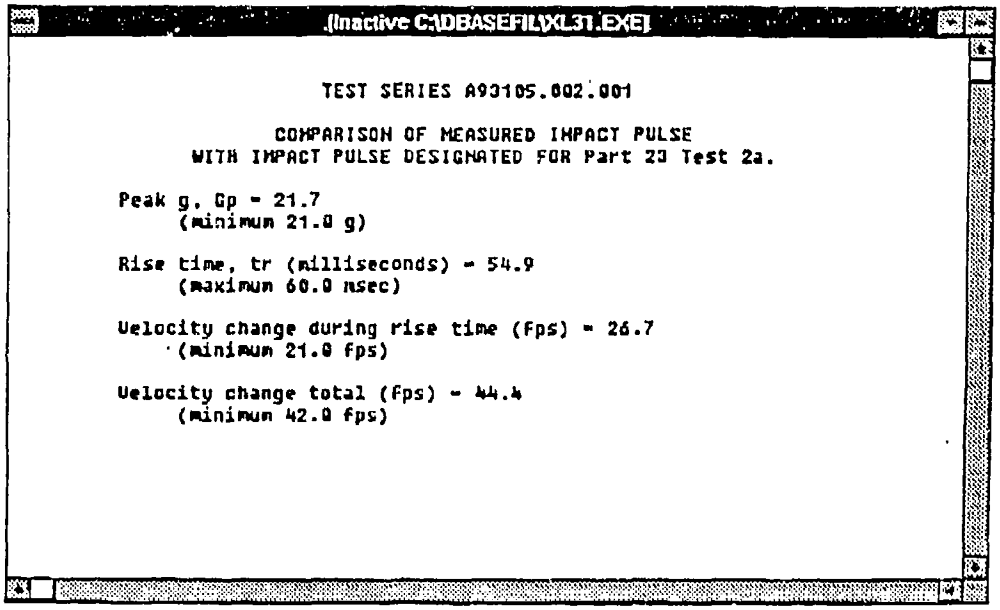


Figure 5.9.2
XL31 Evaluation Results

5.9.3) Plotting Signals with DSP Plot

In addition to Impax, DSP technologies Inc. provided the data acquisition system with plotting software to graphically display test data. This package is called DSP Plot. In this section a brief description on how to use some of its basic features is presented.

As with any Microsoft Windows application, access the package by double clicking on the DSP Plot icon in the Windows program manager. This will bring up the main menu that contains the options File, Signal, Display, Window, and Utilities. To plot a signal from a specific test choose "Signal". Upon clicking on this option a list with different items is presented. Pick the item "Select" and a window like the one shown in figure 5.9.3 will be displayed. In this window, in the group "File Name", choose the desired signal to be plotted. Click on the "Add" box to bring the selected signal to the "Current Signals" group. When the signal is selected it will be highlighted in black as shown in the figure. All signals in this group will be plotted simultaneously on the same graph. Repeat the same process if more signals are to be added. A total of four signals can be plotted at once. Signals can be removed, inserted or replaced from the "Current Signals" group. This window allows the user to select the appropriate directory from which signals are to be retrieved. Once the desired signal is selected click on the "OK" box to execute the selection. This action will close this window and a graph with the selected signal will be displayed. Initially the graph is presented with the system default values. These values can be changed using the "Display" option of the main menu. It is customary

to change the time scale of the horizontal axis so that it spans over a period of 0.40 seconds. The vertical scale is also set to a common scale. The vertical scale is set to either ±21.5 or ±25 g's depending on the peak G level for the test. This is done to aid in comparing deceleration pulses from previous tests. A typical deceleration pulse plotted with this software is shown in figure 5.9.4 above. The "Utility" option allows the user to annotate text to the plots. A print out of the graph can be made using the "Print" item in the "Display" option. To exit

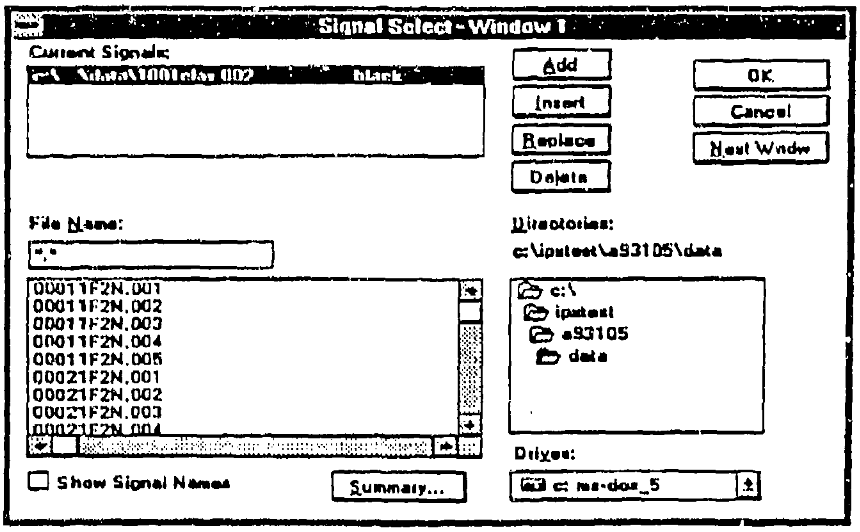


Figure 5.9.3
DSP Plot Signal Select Form

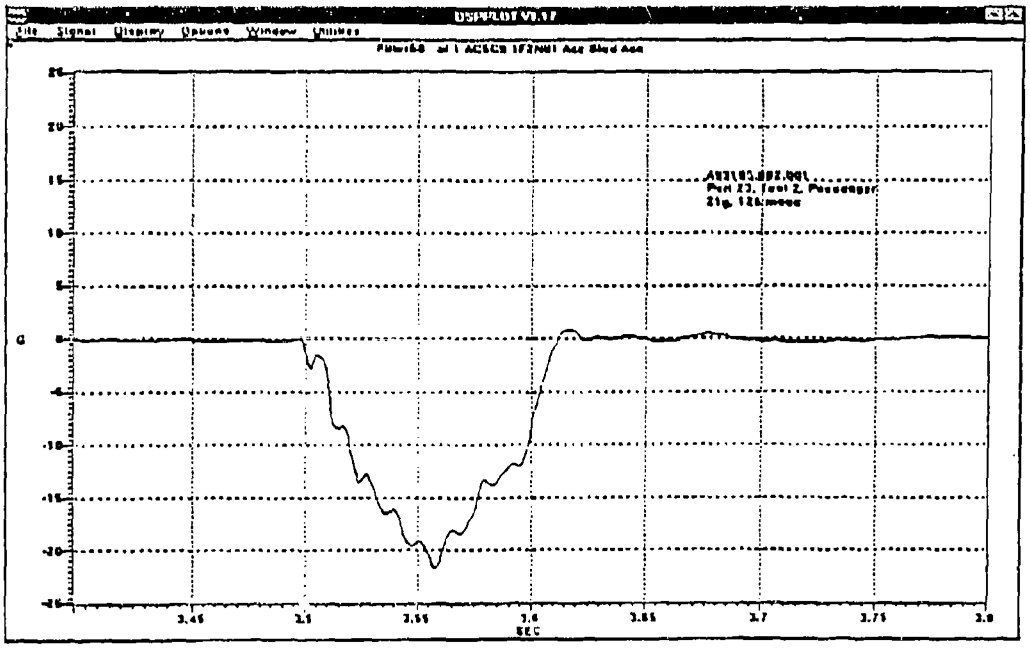


Figure 5.9.4
DSP Plot Graph

the program choose "Exit" under the "File" option. This will close the DSP Plot window displaying the Windows program manager back on the screen.

As with Impax, this software presents numerous useful features. Time could be spent trying to describe them but that is not the scope of this report. The reader is encouraged to read the reference manuals and use the software to learn about all these features.

6.) Some Brief Procedural Explanations

Many tests have been run since the laboratory first started operation. As a result of these tests certain things were learned that were not intuitively obvious in the beginning. Much of what has been learned has developed into what are now the standard operating procedures. This section will attempt to describe the background of some of these procedures. Other aspects that were overlooked or unforeseen but have had a profound effect on the operation of the sled will also be covered.

6.1) The Sled

6.1.1) Oiling the Track

The sled rides on four delrin plastic pads or shoes. If the same impact velocity is to be achieved over a series of tests, the friction force between the shoes and rails should be as consistent as possible. As was described earlier the rails are oiled and wiped prior to each run. The oiling is done primarily to remove dirt from the rails and residue from the sled shoes that accumulates from shoe wear. This oiling procedure will determine the amount of friction between the shoes and the rails. The oiling procedure must therefore be as consistent as possible in order to make the sled speeds repeatable. Over time the oiling procedure has varied from having no oil on the rails to having an excessive amount of oil.

When the rails were not oiled at all the impact velocity of the sled tended to be several feet per second less than desired, whereas when the rails have been heavily oiled and left unwiped, the speed of the sled has increased by several feet per second. For one test instead of using the normal oiling procedure, the rails were sprayed with oil and left unwiped. The impact velocity was 48 ft/s as opposed to the 42 ft/s of the previous test that had the same propulsion system pressure and delay. This was an extreme case but nonetheless shows the variations that can occur due to changes in the amount of oil on the rails.

Since it is hard to predetermine how much to oil the rails, the best way to achieve a consistent speed is to have the same person oil the rails for a given series of tests. This will provide for the best possible consistency.

The reason the oiling procedure still exists, instead of running with dry tracks every time, is because of the residue left behind by the shoes of the sled. The plastic shoes will wear down over time. Most of this wear comes from the initial acceleration of the sled. The use of the oil on the rails has consistently been the best method for cleaning them before each run.

6.1.2) Exercising the Sled

In section 5.2.2 the procedure for exercising the sled was presented. The intent of exercising the sled is to help keep the impact velocity of the sled consistent. Originally, the mechanism used to control the delay time was very inaccurate. This allowed the impact velocity to vary several feet per second between similar tests. The first test of the day always had a slightly lower impact velocity than succeeding tests, and at first this was attributed to the inaccuracies of the delay timer. To determine if the delay timer was indeed the cause of this problem several tests were run with the delay time set to ten seconds. Since a test only lasts between three to four seconds, the delay time effect on the

valves closing at different times was eliminated. These tests helped confirm that the sled performed differently on the first run of the day. The ideal of exercising the sled to "warm up" the system came about as a result of these tests.

Exercising the sled consists of opening and closing the safety and firing valves several times at the beginning of each day, and firing of the sled with just enough pressure to get it down the track. After this procedure was initiated the first run of each day had impact velocities consistent with runs made later in the day.

It is important to note that the exercising procedure should be done prior to the first test of the day as opposed to first thing in the morning. In the past the sled would be exercised, for instance, at eight o'clock in the morning, but the first test of the day was not run until the late afternoon. When this situation occurred, the impact velocity was again slower than expected as if the sled had not been exercised. When the first sled run of the day had to wait until the afternoon, the exercising procedure was performed in the afternoon also. This eliminated any further problems with the impact velocity.

6.1.3) Probe Alignment

The sled probe is essentially a cantilevered beam. When the probe impacts the straps the probe is forced toward the clamp cage and down. As was explained in section 5.2.5, the probe alignment is checked prior to each test. This enables the sled operator to check whether the probe will clear the restraining system lateral cross member.

During the first several test runs the need to check the alignment of the probe was not known and the upper probe contacted the lateral cross member. This impact caused the upper probe to buckle. A new probe had to be ordered from the sled manufacturer and took several months to arrive. During this time no work could be performed in the lab. If this had occurred at the present time the loss of several months could mean the loss of substantial revenue and cause setbacks for research work done in the lab.

The importance of checking the alignment of the probe can not be over stated. Checking and changing the alignment is a relatively simple and non time consuming procedure. When there is even the slightest doubt about the probe, it is better to realign it and be sure it is ok than to go on to the next test.

6.1.4) Removal of Sled Components

There are many pieces that make up the impact sled. There are the probes, the template plate, the substructure, and the sled's cross members as well as other parts. In section 6.1.1 the need to keep the friction force between the sled and the tracks constant was explained. Each component of the sled contributes in some way to the normal force that the sled exerts on the tracks. If one of the sled components is for some reason removed this normal force will be altered changing the friction force, which will change the speed of the sled.

As an example, the upper probe was once removed for some modifications. During this time several tests needed to be run so extra ballast weight was added to compensate for the weight of the probe. The impact velocity, however, was higher than expected. Since the center of gravity of the probe is several feet in front of the sled template the probe will produce a moment on the rest of the sled. This moment will try to force the front of the sled down and pull up on the back. When the upper probe was removed and

replaced with ballast weight the distribution of sled weight on the shoes was changed. This changed the friction force between the sled and the tracks thus changing the impact velocity.

When creating a new pulse, it is a good idea to try to simulate the actual test payload as closely as possible. This will help in achieving the proper speed when an actual test is performed. Simulating a typical payload also helps in refining the pulse shape.

6.1.5) Securing the Payload to the Sled

Test articles, fixtures and ballast plates should be secured to the sled as tightly as possible. There are three main reasons for this. One is to prevent anything from flying off the sled at impact. The another is to prevent the movement of fixtures of ballast plates from affecting the pulse shape, and the third reason is to provide a rigid support for the test article. If the test fixtures move at impact the test may be invalid.

The test article will normally be secured to either the sled template or one of the labs' fixtures. During the impact the fixtures should remain rigid. It is therefore of great importance to make sure that the fixturing is tightly secured to the sled. If one of the test fixtures moves during a test it is possible that the test will be invalid. The bolts that secure the fixturing to the sled should be checked prior to each test.

Some fixtures need to be subjected to one impact before the actual test is performed. The 60° pitch fixtures require an initial impact to set them in place. These fixtures have enough mounting bolts and hole tolerance to allow some movement. The position the fixture is initially placed will usually not be the position after several tests.

Fixtures or ballast plates with oversized holes should be pushed toward the front of the sled. This will bring the bolt hole in contact with the bolt, restricting as much of the movement as possible.

6.1.6) Movement of ATDs During Impact

The weight of the payload on the sled is kept fixed for similar tests. This fixed mass system allows the decelerator setup to remain constant. The use of anthropomorphic test dummies, ATDs, will complicate this fixed mass system because for some types of tests the dummy(s) will continue moving at impact. The force that the sled is subjected to is the mass times the acceleration, in the sled's forward direction, of the sled and payload. When an ATD continues moving at impact the mass of the sled will appear lighter. This will cause the straps to appear stiffer than necessary thus increasing the impact acceleration of the sled.

This movement of the test dummies was not taken into account when the first pulses were originally developed. One pulse was developed with only ballast plates and then run with a seat and dummy setup. The ballast plate pulse achieved an acceptable 21.3 G peak deceleration, but when the ATD and seat were run, the peak G level for the same strap combination was 23.3. After this test all pulses for single seat tests were developed using the iron seat and a dummy.

This situation helps to show the importance of taking into account the ATD movement. At present any new pulses are developed with a representative payload. The number of ATDs that are required for a given test needs to be used in pulse development

in order to achieve the desired pulse shape. A method of developing pulses using ballast plates while taking into account the movement of the ATDs is currently being developed.

6.2) The Restraining System

6.2.1) Clamping the Straps

The sled will be traveling between thirty and forty-five feet per second at impact. The one of the most important thing to do for any test is to make sure the restraining system straps are present and clamped. The clamping of the straps needs to be checked and rechecked for two reasons. The first reason is the safety of the sled. If the straps are not clamped, there is a very good possibility that the sled will be damaged. The other reason is to ensure the proper deceleration pulse. The clamp cage must be closed as far as possible and the pressure roller must be pulled back to the proper spot.

It is the responsibility of every person who loads the straps to make sure both the roller and clamp cages are clamped. If there is ever any doubt as to the state of the restraining system, it should be checked prior to firing the sled.

6.2.2) Checking the Rollers

The rollers on the probes of the sled and the restraining system must roll freely. If a roller binds or needs to be forced to turn, the friction force between the roller and the straps will change. This will change the acceleration versus time curve raising the peak G level for the pulse.

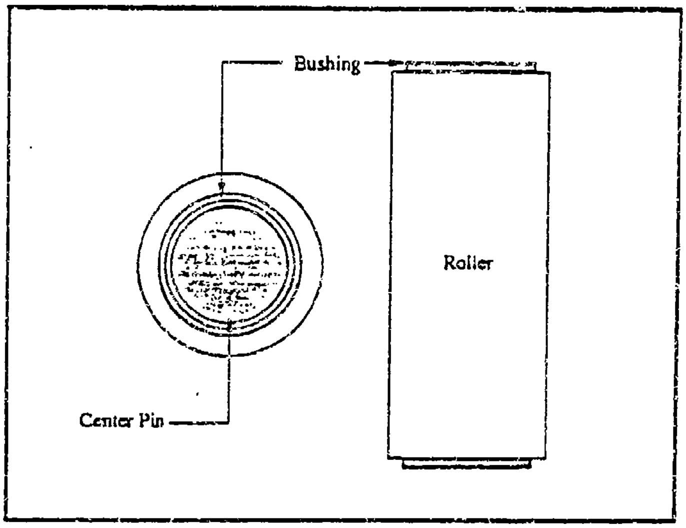


Figure 6.2.1
Typical Roller

Each roller has a stainless steel center pin about which to rotate. These pins need to be periodically cleaned and oiled to keep them rolling freely. The outer surface of the roller should be kept clear of nicks and scratches. One problem that can sometimes occur is for the bushings inside the roller work their way out. When this happens, the rollers will bind. To repair this the center pin should be removed and the roller taken out. The bushing, shown in figure 6.2.1, must be tapped back into place.

Once in the past the two bolts that hold the idle roller reinforcement arm in place were tightened too far. This caused the two bolts to come in contact with the number two roller, shown in figure 3.3.2. The two bolts were only slightly touching the roller yet caused what would normally be a 15 G pulse to have a 17 G peak.

This is the reason the rollers have to be checked prior to each test. The probe rollers should be rotated before the sled is fired and the ones in the roller cage need to be checked before straps are loaded. If any roller does not spin freely it must be fixed before the test is run so the deceleration pulse is not affected.

6.2.3) The All Thread Rod

The all thread rod that runs between the clamp and roller cages is there to help resist the forces of the impact. When the probe contacts the straps both of the cages are pulled toward the probe by the tension in the straps. The all thread rod assists the two bolts that attach the cages to the lateral cross member. There are some impacts where the attachment bolts might be able to withstand the impact forces by themselves, but usually they are not enough.

During the static tests some of the force versus displacement profiles for pulses were attempted. One pulse was run at the 62.25" stance. At this stance the all thread rod was too short to be used so it was omitted. During the test the two attachment bolts on the roller cage sheared off. There was no damage as a result of this since it was only a static test however if this had occurred during a dynamic test the consequences may have been more severe.

The all thread rod should always be in place and tight prior to firing the sled. This is another situation where a failure to follow the set procedures of the lab might result in permanent damage to the sled or restraining system.

6.3) Impax

6.3.1) Setting Correct Sensitivities

Each transducer used for a test is entered into the Impax database. Devices are controlled and recorded through Impax. The transducers are electronic devices that output changes in the voltage due to an applied load. These voltage changes are converted into engineering units through its sensitivity value. The sensitivity value must be correct in order to convert a transducer's output into engineering units.

When a new transducer is entered into the transducer data file in Impax, information such as the sensitivity, excitation voltage, and full scale value is entered. Once a device is in the transducer data file these values will remain the same for any test. The sensitivity must be entered as volts per volt per unit. When a device is delivered there is a data sheet that lists all of the information that is required. The sensitivity will be listed on this sheet, however, it may not be in the correct units.

If there is ever a question about a reading from a device the sensitivity should be one of the first things that is checked. An incorrect sensitivity or amplifier excitation voltage are two of the main causes of data errors.

6.3.2) Setting Correct Excitation Voltages

When a transducer is connected to the data system it is connected to an amplifier. This amplifier, among other things, supplies an excitation voltage to the device. Since each device is configured to run at a specific excitation voltage the amplifier must be correctly set in order for the device to read properly. The excitation voltage for a transducer can be found listed on the data sheet that comes with it or in a catalog from the manufacturer.

Prior to running a test the excitation voltages of the transducers being used should be checked. The default setting for excitation voltage on the amplifiers is set to 10 volts. Devices like sled accelerometers that run at 15 volts excitation will read improperly at the 10 volt setting. Since sled acceleration must be known in order to evaluate a deceleration pulse, the loss of this data due to an incorrect excitation voltage is a very serious occurrence. Several times the amplifier voltage was set for 15 volts one day, but on the following day it had reset itself to 10 volts. The occurrence of this has been rare but must be taken into consideration prior to every test.

7.) References

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Appendix

```
     ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c                              Program Pulse
c                            JCR and KWP ©1992
c                         Theory presented in section 4
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c This code will select a set of straps to match a set of input test conditions.
c The user inputs the peak G level, impact velocity, and sled payload weight.
c The code will then select a stance and a set of straps to be used for the initial
c attempt at the pulse.
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c     g              = Gravity, 32.2 ft/s^2
c     gpeakt         = the peak g level of the ideal pulse
c     inum(i)        = an integer array containing the number of each type of strap
c     iprobe         = flag to determine if one or two probes are used
c     istance        = a flag to determine which stance is currently being used
c     istrap         = a flag to determine which size strap is currently being used
c     maxstrap       = the maximum force at the peak for one strap
c     pload316       = the peak load attainable with 3/16" straps
c     pload(i)       = an array of loads for each size strap at a given stroke and stance
c     ploada         = the peak load attainable for a given stance
c     plaods         = the load the straps will produce based on static data
c     ploadsp        = the max load possible using only one probe
c     ploadt         = the load at the peak for the ideal pulse
c     ploadt2        = the load the straps will actually try to match
c     resp           = a character variable used for yes/no questions
c     sheight        = the total height of the strap combination
c     smass          = the mass of the sled including payload
c     strapno        = the number of straps needed to achieve ploadt
c     strapsize(i)   = an array of the strap widths
c     strokep        = the stroke at the peak of the ideal pulse
c     stroket        = the total stroke of the ideal pulse
c     tau            = the pulse duration
c     vo             = the impact velocity of the sled
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
      implicit real*8(a-h,o-z),integer(i-n)
      ch   -ter*1 resp
      dimension inum(4),pload(4)
      common/sdata/strapsize(4)
      parameter(g=32.2d0)
      iprobe=1
ccccccccccccccccccccccccccccccccccccccccccccccccc
c The user specifies the weight of the payload on the sled
ccccccccccccccccccccccccccccccccccccccccccccccccc
      write(5,*)' Enter the mass of the total sled payload'
      read(5,*) smass
```

```
        smass=smass+1379.0d0
cccccccccccccccccccccccccccccccccccccccccccccccc
c--> Ask user for peak G level and pulse duration
c    also enter the payload mass and add to the
c    sled mass
cccccccccccccccccccccccccccccccccccccccccccccccc
        write(5,*)' Enter the peak G level '
        read(5,*) gpeakt
        write(5,*)' Do you wish to enter the impact velocity '
        write(5,*)' or the pulse duration ?'
2       write(5,*)' Enter "V" for velocity or "D" for duration'
        read(5,'(a1)')resp
        if(resp.eq.'v'.or.resp.eq.'V')then
                write(5,*)' Enter the impact velocity in fps.'
                read(5,*)vo
                goto 10
        elseif(resp.eq.'d'.or.resp.eq.'D')then
                write(5,*)' Enter the pulse duration in milliseconds'
                read(5,*) tau
        else
                goto 2
        endif
cccccccccccccccccccccccccccccccccccccccccccccccccccc
c  If the pulse duration is entered
c--> From Gpeak and tau determine the initial velocity
c--> Then find the closest aplicable velocity
cccccccccccccccccccccccccccccccccccccccccccccccccccc
        vo=g*gpeakt*tau/2000.0d0
        write(5,*)'  Velocity  Duration'
        write(5,1)vo,tau
        if(vo.ge.17.5d0.and.vo.lt.22.5d0)then
                vo=20.0d0
        elseif(vo.ge.22.5d0.and.vo.lt.27.5d0)then
                vo=25.0d0
        elseif(vo.ge.27.5d0.and.vo.lt.32.5d0)then
                vo=30.0d0
        elseif(vo.ge.32.5d0.and.vo.lt.37.5d0)then
                vo=35.0d0
        elseif(vo.ge.37.5d0.and.vo.lt.42.5d0)then
                vo=40.0d0
        elseif(vo.ge.42.5d0.and.vo.lt.47.5d0)then
                vo=45.0d0
        elseif(vo.ge.47.5d0.and.vo.lt.52.5d0)then
                vo=50.0d0
        elseif(vo.ge.52.5d0.and.vo.lt.57.5d0)then
```

```
            vo=55.0d0
        elseif(vo.ge.57.5d0.and.vo.lt.62.5d0)then
            vo=60.0d0
        elseif(vo.ge.62.5d0.and.vo.lt.67.5d0)then
            vo=65.0d0
        elseif(vo.ge.67.5d0.and.vo.lt.72.5d0)then
            vo=70.0d0
        elseif(vo.ge.72.5d0.and.vo.lt.77.5d0)then
            vo=75.0d0
        endif
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c--> Recalculate the value of tau to reflect the new velocity
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
10      tau=2.0d0*vo/(g*gpeakt)
cccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c--> Determine the stroke at the peak and the total stroke
c   stroke at the peak is given by s(T/2)=5/12*Vo*T
c   stroke total is given by s(T)=6/12*Vo*T
c   Strokes are calculated in inches
cccccccccccccccccccccccccccccccccccccccccccccccccccccccc
        strokep=5.0d0/12.0d0*vo*tau*12.0d0
        stroket=0.5d0*vo*tau*12.0d0
        write(5,20)strokep,stroket
20      format(' Peak stroke = ',f12.5,' Total stroke = ',f12.5)
ccccccccccccccccccccccccccccccccccccccccccccc
c--> Find the peak load for the ideal pulse
ccccccccccccccccccccccccccccccccccccccccccccc
        ploadt=gpeakt*smass
cccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c--> Calculate the maximum load possible with one probe
cccccccccccccccccccccccccccccccccccccccccccccccccccccccc
        call straps(pload200,strokep,4,1)
        call straps(pload050,strokep,4,7)
11      ploadsp=3.25*pload200+pload050
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c--> if pulse cannot be achieved with one probe then attempt with
c   two probes with both stances the same and both strap setups
c   the same on top and bottom
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
        if(ploadt.ge.ploadsp)then
            if(iprobe.eq.2)then
                goto 100
            else
                write(5,*)' Attempting with two probes ........'
                iprobe=2
```

```
                ploadt=ploadt/2.0d0
                goto 11
            endif
        endif
cccccccccccccccccccccccccccccccccccccccccccccccccccccc
c--> Starting with the largest stance loop through stances
c   until a stance is found where the pulse can be achieved
cccccccccccccccccccccccccccccccccccccccccccccccccccccc
        istance=2
        do 3 i=2,4
            call straps(pload200,strokep,istance,1)
            call straps(pload050,strokep,istance,7)
            ploada=3.25d0*pload200+pload050
            if(ploada.gt.ploadt)goto 4
            istance=istance+1
3       continue
cccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c--> Determine if the pulse can be achieved with 3/16" straps
cccccccccccccccccccccccccccccccccccccccccccccccccccccccc
4       call straps(pload200,strokep,istance,4)
        call straps(pload050,strokep,istance,8)
        pload316=3.25*pload200+pload050
        if(pload316.gt.(ploadt+6500.0))then
            istart=6
            ihalf=8
        else
            istart=3
            ihalf=7
        endif
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c--> Loop through the different strap sizes starting with the
c  smallest to the largest.
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c--> Determine the load each of the 4 strap sizes will produce
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
        call straps(pload(1),strokep,istance,istart-2)
        call straps(pload(2),strokep,istance,istart-1)
        call straps(pload(3),strokep,istance,istart)
        call straps(pload(4),strokep,istance,ihalf)
cccccccccccccccccccccccccccccccccccc
c--> Begin with the smallest strap
cccccccccccccccccccccccccccccccccccc
        ploadt2=ploadt+6500.0d0-pload(4)
        i=3
cccccccccccccccccccccccccccccccc
```

```
c--> Zero the number of straps
cccccccccccccccccccccccccccccccc
9     inum(1)=0
      inum(2)=0
      inum(3)=0
      inum(4)=0
      strapno=(ploadt2)/pload(i)
      inum(i)=int(strapno)
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c--> If the decimal part is greater than 0.5 then add another full strap
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
      decimal=strapno-real(inum(i))
      if(decimal.gt.0.6d0)then
          inum(i)=inum(i)+1
          goto 6
      endif
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c--> Split the decimal strap height into an equivalent number of half
c    inch straps
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
      inum(4)=int((strapno-real(inum(i)))*strapsize(i)/0.5d0)
      term=(strapno-real(inum(i)))*strapsize(i)/0.5d0
      if(term.gt.0.5d0.and.term.lt.1.0d0)then
          inum(4)=inum(4)+1
      endif
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c--> Calculate the total height of the straps, if greater than 6.5"
c    then start again with the next larger strap size
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
6     sheight=real(inum(1))*strapsize(1)+real(inum(2))*strapsize(2)
   +      +real(inum(3))*strapsize(3)+real(inum(4))*strapsize(4)
      if(sheight.gt.6.5d0)then
          i=i-1
          if(i.eq.0)goto 8
          goto 9
      endif
cccccccccccccccccccccccccccccccccccccccccccccccccccc
c--> Determine the total load produced by the straps
cccccccccccccccccccccccccccccccccccccccccccccccccccc
      ploads=real(inum(1))*pload(1)+real(inum(2))*pload(2)
   +      +real(inum(3))*pload(3)+real(inum(4))*pload(4)
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c--> If the strap load is less than the necessary load then
c    replace one of the straps with one of the next size larger
c    and repeat the process. If the number of the current straps
```

```
c    goes to zero then restart with the next bigger size.
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
      if(ploads.lt.ploadt2)then
            inum(i)=inum(i)-1
            if(inum(i).eq.0)then
                  i=i-1
                  goto 9
            endif
            inum(i-1)=inum(i-1)+1
            goto 5
      endif
8     if(iprobe.eq.2)ploads=ploads*2.0d0
ccccccccccccccccccccccc
c--> output setup
ccccccccccccccccccccccc
      write(5,*)' '
      if(istance.eq.1)then
            write(5,*)' Stance is 62.25"'
      elseif(istance.eq.2)then
            write(5,*)' Stance is 52.25"'
      elseif(istance.eq.3)then
            write(5,*)' Stance is 32.25"'
      elseif(istance.eq.4)then
            write(5,*)' Stance is 17.25"'
      endif
      if(ihalf.eq.7)then
            write(5,*)' Straps are 1/4 inch thick'
      else
            write(5,*)' Straps are 3/16 inch thick'
      endif
      write(5,*)' '
      write(5,7)inum(1),strapsize(1)
      write(5,7)inum(2),strapsize(2)
      write(5,7)inum(3),strapsize(3)
      write(5,7)inum(4)+1,strapsize(4)
      write(5,*)' '
      write(5,15)sheight+strapsize(4)
      if(iprobe.eq.2)ploadt=2.0d0*ploadt
      write(5,13)ploadt
      write(5,17)ploads
      write(5,16)ploada
1     format(2(2x,f10.5))
7     format(' ',i2,' straps of width ',f5.2,' are needed')
13    format(' Peak load necessary is ',f12.5)
14    format(' Strap Numbers 2.0->0.5  ',i2,2x,i2,2x,i2,2x,i2)
```

```
15    format(' Total strap height including the safety stra  is ',f5.2
   +)
16    format(' The Max possible load is ',f12.5)
17    format(' The load from the straps wil be ',f12.5)
100    stop
      end

      block data strapdata
      implicit double precision(a-h,o-z)
      implicit integer(i-n)
      common/sdata/strapsize(4)
      data strapsize(1)/2.00d0/
      data strapsize(2)/1.50d0/
      data strapsize(3)/1.25d0/
      data strapsize(4)/0.50d0/
      end
```

```
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c                           Subroutine Straps
c                          JCR and KWP ©1992
c                      Theory presented in section 4
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c    This subroutine recieves two flags, one which determines
c  which stance to use, and another to determine which strap to use.
c  The stroke of the sled in inches is also input and the load
c  produced by the given strap for the given displacement is found
c  based on the static data.
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c  Variable definitions
c    A#      = the coefficients of the curve fit equations
c    istance = the flag which determines which stance to use
c    istrap  = the flag which determines which strap to use
c    sload   = the load produced by the strap
c    x       = the stroke of the sled in inches
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c  Integer flags definition
c-------------------------------------------------------------
c   Stance Flags
c-------------------------------------------------------------
c    istance=1 -> 62.25" stance
c    istance=2 -> 52.25" stance
c    istance=3 -> 32.25" stance
c    istance=4 -> 17.25" stance
c-------------------------------------------------------------
c   Strap Flags
c-------------------------------------------------------------
c    istrap=1 -> 2.00 x 1/4  strap
c    istrap=2 -> 1.50 x 1/4  strap
c    istrap=3 -> 1.25 x 1/4  strap
c    istrap=4 -> 2.00 x 3/16 strap
c    istrap=5 -> 1.50 x 3/16 strap
c    istrap=6 -> 1.25 x 3/16 strap
c    istrap=7 -> 0.50 x 1/4  strap
c    istrap=8 -> 0.50 x 3/16 strap
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
      subroutine straps(sload,x,istance,istrap)
      implicit double precision(a-h,o-z)
      implicit integer(i-n)
cccccccccccccccccccccccccccccc
c Data for stance of 17.25" c
cccccccccccccccccccccccccccccc
      if(istance.eq.4)then
```

```
cccccccccccccccccccccccccccccccccccccccccccc
c  Static Test Data for test S91000.001      c
c  2.00" x 1/4" strap    stance: 17.25"      c
cccccccccccccccccccccccccccccccccccccccccccc
          if(istrap.eq.1)then
               A0= -275.485997287
               A1=  903.054400170
               A2=  490.563023444
               A3=  -60.460287245
               A4=    2.965804101
               A5=    -.067801237
               A6=     .000598581
               sload=A0+A1*X+A2*X**2+A3*X**3+A4*X**4+A5*
     +          X**5+A6*X**6
cccccccccccccccccccccccccccccccccccccccccccc
c  Static Test Data for test s91000.003      c
c  1.50" x 1/4" strap    stance: 17.25"      c
cccccccccccccccccccccccccccccccccccccccccccc
          elseif(istrap.eq.2)then
               A0= -290.175547956
               A1=  939.492432195
               A2=  270.584950295
               A3=  -33.541427493
               A4=    1.562256194
               A5=    -.033375376
               A6=     .000273414
               sload=A0+A1*X+A2*X**2+A3*X**3+A4*X**4+A5*
     +          X**5+A6*X**6
cccccccccccccccccccccccccccccccccccccccccccc
c Static Test Data for test s91000.005       c
c 1.25" x 1/4" strap    stance: 17.25"       c
cccccccccccccccccccccccccccccccccccccccccccc
          elseif(istrap.eq.3)then
               A0= -219.400312649
               A1=  851.134598851
               A2=  233.937446138
               A3=  -30.140954289
               A4=    1.441048515
               A5=    -.031341649
               A6=     .000259398
               sload=A0+A1*X+A2*X**2+A3*X**3+A4*X**4+A5*
     +          X**5+A6*X**6
cccccccccccccccccccccccccccccccccccccccccccc
c  Static Test Data for test S91000.00-      c
c  0.50" x 1/4" strap    stance: 17.25"      c
```

```
c NOTE: this curve is obtained by dividing   c
c    the 2.00 x 1/4 curve by 4              c
cccccccccccccccccccccccccccccccccccccccccccc
          elseif(istrap.eq.7)then
               A0= -275.485997287
               A1=  903.054400170
               A2=  490.563023444
               A3=  -60.460287245
               A4=    2.965804101
               A5=    -.067801237
               A6=     .000598581
               sload=(A0+A1*X+A2*X**2+A3*X**3+A4*X**4+A5*
     +          X**5+A6*X**6)/4.0d0
cccccccccccccccccccccccccccccccccccccccccccc
c Static Test Data for test s91000.007      c
c 2.00" x 3/16" strap   stance: 17.25"      c
cccccccccccccccccccccccccccccccccccccccccccc
          elseif(istrap.eq.4)then
               A0=  -12.818319677
               A1=  216.218213996
               A2=  394.874716152
               A3=  -55.635807541
               A4=    3.518853888
               A5=    -.119056799
               A6=     .002093364
               A7=    -.000015030
               sload=A0+A1*X+A2*X**2+A3*X**3+A4*X**4+A5*
     +          X**5+A6*X**6+A7*X**7
cccccccccccccccccccccccccccccccccccccccccccc
c Static Test Data for test s91000.009      c
c 1.50" x 3/16" strap   stance: 17.25"      c
cccccccccccccccccccccccccccccccccccccccccccc
          elseif(istrap.eq.5)then
               A0=  135.417640581
               A1=   38.334804433
               A2=  298.082405432
               A3=  -44.162706974
               A4=    2.956779234
               A5=    -.104812043
               A6=     .001906770
               A7=    -.000014011
               sload=A0+A1*X+A2*X**2+A3*X**3+A4*X**4+A5*
     +          X**5+A6*X**6+A7*X**7
cccccccccccccccccccccccccccccccccccccccccccc
c Static Test Data for test s91000.011      c
```

```
c 1.25" x 3/16" strap   stance: 17.25"      c
ccccccccccccccccccccccccccccccccccccccccccccc
          elseif(istrap.eq.6)then
                A0=  63.819047445
                A1=  113.986592310
                A2=  258.783700690
                A3= -37.065818907
                A4=    2.404702081
                A5=   -.083306012
                A6=    .001491081
                A7=   -.000010829
                sload=A0+A1*X+A2*X**2+A3*X**3+A4*X**4+A5*
     +           X**5+A6*X**6+A7*X**7
ccccccccccccccccccccccccccccccccccccccccccccc
c Static Test Data for test s91000.00-      c
c 0.50" x 3/16" strap   stance: 17.25"      c
c NOTE: this curve is obtained by dividing  c
c    the 2.00 x 3/16 curve by 4             c
ccccccccccccccccccccccccccccccccccccccccccccc
          elseif(istrap.eq.8)then
                A0= -12.818319677
                A1=  216.218213996
                A2=  394.874716152
                A3= -55.635807541
                A4=    3.518853888
                A5=   -.119056799
                A6=    .002093364
                A7=   -.000015030
                sload=(A0+A1*X+A2*X**2+A3*X**3+A4*X**4+A5*
     +           X**5+A6*X**6+A7*X**7)/4.0d0
          endif
cccccccccccccccccccccccccccccc
c Data for stance of 32.25" c
cccccccccccccccccccccccccccccc
        elseif(istance.eq.3)then
ccccccccccccccccccccccccccccccccccccccccccccc
c Static Test Data for test s91001.001      c
c 2.00" x 1/4" strap    stance: 32.25"      c
ccccccccccccccccccccccccccccccccccccccccccccc
          if(istrap.eq.1)then
                A0= -58.846723301
                A1=  566.953790013
                A2=  140.508089583
                A3= -10.165969315
                A4=    .271979930
```

```
          A5=  -.002616201
          sload=A0+A1*X+A2*X**2+A3*X**3+A4*X**4+A5*X**5
cccccccccccccccccccccccccccccccccccccccccccccccc
c Static Test Data for test s91001.003       c
c 1.50" x 1/4" strap   stance: 32.25"        c
cccccccccccccccccccccccccccccccccccccccccccccccc
       elseif(istrap.eq.2)then
          A0= -387.463314235
          A1=  346.333081351
          A2=  138.308131200
          A3=  -12.017183053
          A4=     .449368187
          A5=    -.008159191
          A6=     .000058530
          sload=A0+A1*X+A2*X**2+A3*X**3+A4*X**4+A5*
     +       X**5+A6*X**6
cccccccccccccccccccccccccccccccccccccccccccccccc
c Static Test Data for test s91001.006       c
c 1.25" x 1/4" strap   stance: 32.25"        c
cccccccccccccccccccccccccccccccccccccccccccccccc
       elseif(istrap.eq.3)then
          A0=  -87.879918049
          A1=  360.617385974
          A2=   88.257781000
          A3=   -6.546254884
          A4=     .177909854
          A5=    -.001729416
          sload=A0+A1*X+A2*X**2+A3*X**3+A4*X**4+A5*X**5
cccccccccccccccccccccccccccccccccccccccccccccccc
c Static Test Data for test s91001.00-       c
c 0.50" x 1/4" strap   stance: 32.25"        c
c NOTE: this curve is obtained by dividing   c
c   the 2.00 x 1/4 curve by 4                c
cccccccccccccccccccccccccccccccccccccccccccccccc
       elseif(istrap.eq.7)then
          A0=  -58.846723301
          A1=  566.953790013
          A2=  140.508089583
          A3=  -10.165969315
          A4=     .271979930
          A5=    -.002616201
          sload=(A0+A1*X+A2*X**2+A3*X**3+A4*X**4+A5*
     +       X**5)/4.0d0
cccccccccccccccccccccccccccccccccccccccccccccccc
c Static Test Data for test s91001.007       c
```

```
c 2.00" x 3/16" strap   stance: 32.25"      c
cccccccccccccccccccccccccccccccccccccccccccccc
          elseif(istrap.eq.4)then
               A0= -79.180471723
               A1= 398.085094071
               A2=  47.801841402
               A3=  -3.455272139
               A4=    .088191581
               A5=   -.000818820
               sload=A0+A1*X+A2*X**2+A3*X**3+A4*X**4+A5*X**5
cccccccccccccccccccccccccccccccccccccccccccccc
c Static Test Data for test s91001.009      c
c 1.50" x 3/16" strap   stance: 32.25"      c
cccccccccccccccccccccccccccccccccccccccccccccc
          elseif(istrap.eq.5)then
               A0=   -.159379147
               A1= 205.062422018
               A2=  42.822241025
               A3=  -2.900467249
               A4=    .068662042
               A5=   -.000560050
               sload=A0+A1*X+A2*X**2+A3*X**3+A4*X**4+A5*X**5
cccccccccccccccccccccccccccccccccccccccccccccc
c Static Test Data for test s91001.012      c
c 1.25" x 3/16" strap   stance: 32.25"      c
cccccccccccccccccccccccccccccccccccccccccccccc
          elseif(istrap.eq.6)then
               A0=  10.257109577
               A1= 231.796813404
               A2=  38.528217158
               A3=  -2.851547493
               A4=    .076846144
               A5=   -.000749934
               sload=A0+A1*X+A2*X**2+A3*X**3+A4*X**4+A5*X**5
cccccccccccccccccccccccccccccccccccccccccccccc
c Static Test Data for test s91001.00-      c
c 0.50" x 3/16" strap   stance: 32.25"      c
c NOTE: this curve is obtained by dividing  c
c   the 2.00 x 3/16 curve by 4              c
cccccccccccccccccccccccccccccccccccccccccccccc
          elseif(istrap.eq.8)then
               A0= -79.180471723
               A1= 398.085094071
               A2=  47.801841402
               A3=  -3.455272139
```

```
            A4=   .088191581
            A5=   -.000818820
            sload=(A0+A1*X+A2*X**2+A3*X**3+A4*X**4+A5*
     +       X**5)/4.0d0
        endif
cccccccccccccccccccccccccccc
c Data for stance of 52.25" c
cccccccccccccccccccccccccccc
      elseif(istance.eq.2)then
cccccccccccccccccccccccccccccccccccccccccccccc
c Static Test Data for test s91002.002       c
c 2.00" x 1/4" strap    stance: 52.25"       c
cccccccccccccccccccccccccccccccccccccccccccccc
        if(istrap.eq.1)then
            A0= -904.769545398
            A1=  881.199201577
            A2=   -6.801137588
            sload=A0+A1*X+A2*X**2
cccccccccccccccccccccccccccccccccccccccccccccc
c Static Test Data for test s91002.004       c
c 1.50" x 1/4" strap    stance: 52.25"       c
cccccccccccccccccccccccccccccccccccccccccccccc
        elseif(istrap.eq.2)then
            A0=  127.592775011
            A1=   17.672848615
            A2=  132.258531099
            A3=  -12.833320539
            A4=     .594060962
            A5=    -.013348962
            A6=     .000115823
            sload=A0+A1*X+A2*X**2+A3*X**3+A4*X**4+A5*
     +       X**5+A6*X**6
cccccccccccccccccccccccccccccccccccccccccccccc
c Static Test Data for test s91002.006       c
c 1.25" x 1/4" strap    stance: 52.25"       c
cccccccccccccccccccccccccccccccccccccccccccccc
        elseif(istrap.eq.3)then
            A0=  125.204208857
            A1=   53.500387252
            A2=  100.926017984
            A3=   -9.572675149
            A4=     .431494196
            A5=    -.009473489
            A6=     .000080610
            sload=A0+A1*X+A2*X**2+A3*X**3+A4*X**4+A5*
```

```
     +              X**5+A6*X**6
cccccccccccccccccccccccccccccccccccccccccccccc
c Static Test Data for test s91002.00-       c
c 0.50" x 1/4" strap    stance: 52.25"       c
c NOTE: this curve is obtained by dividing   c
c    the 2.00 x 1/4 curve by 4               c
cccccccccccccccccccccccccccccccccccccccccccccc
            elseif(istrap.eq.7)then
                  A0= -904.769545398
                  A1=  881.199201577
                  A2=   -6.801137588
                  sload=(A0+A1*X+A2*X**2)/4.0d0
cccccccccccccccccccccccccccccccccccccccccccccc
c Static Test Data for test s91002.007       c
c 2.00" x 3/16" strap   stance: 52.25"       c
cccccccccccccccccccccccccccccccccccccccccccccc
            elseif(istrap.eq.4)then
                  A0=  100.211523922
                  A1=   21.590205944
                  A2=   94.890893929
                  A3=   -9.597254877
                  A4=     .452892048
                  A5=    -.010213338
                  A6=     .000088392
                  sload=A0+A1*X+A2*X**2+A3*X**3+A4*X**4+A5*
     +              X**5+A6*X**6
cccccccccccccccccccccccccccccccccccccccccccccc
c Static Test Data for test s91002.010       c
c 1.50" x 3/16" strap   stance: 52.25"       c
cccccccccccccccccccccccccccccccccccccccccccccc
            elseif(istrap.eq.5)then
                  A0=   25.099562611
                  A1=  176.907644747
                  A2=   15.403956010
                  A3=   -1.409056143
                  A4=     .065907469
                  A5=    -.001551940
                  A6=     .000013821
                  sload=A0+A1*X+A2*X**2+A3*X**3+A4*X**4+A5*
     +              X**5+A6*X**6
cccccccccccccccccccccccccccccccccccccccccccccc
c Static Test Data for test s91002.012       c
c 1.25" x 3/16" strap   stance: 52.25"       c
cccccccccccccccccccccccccccccccccccccccccccccc
            elseif(istrap.eq.6)then
```

```
              A0=  -68.376647138
              A1=  182.173728240
              A2=  20.094183790
              A3=  -1.929966510
              A4=   .085488978
              A5=  -.001861684
              A6=   .000015649
              sload=A0+A1*X+A2*X**2+A3*X**3+A4*X**4+A5*
     +         X**5+A6*X**6
ccccccccccccccccccccccccccccccccccccccccccc
c Static Test Data for test s91002.00-      c
c 0.50" x 3/16" strap   stance: 52.25"      c
c NOTE: this curve is obtained by dividing  c
c    the 2.00 x 3/16 curve by 4             c
ccccccccccccccccccccccccccccccccccccccccccc
           elseif(istrap.eq.8)then
              A0=  100.211523922
              A1=  21.590205944
              A2=  94.890893929
              A3=  -9.597254877
              A4=   .452892048
              A5=  -.010213338
              A6=   .000088392
              sload=(A0+A1*X+A2*X**2+A3*X**3+A4*X**4+A5*
     +         X**5+A6*X**6)/4.0d0
           endif
ccccccccccccccccccccccccccccc
c Data for stance of 62.25" c
ccccccccccccccccccccccccccccc
        elseif(istance.eq.1)then
ccccccccccccccccccccccccccccccccccccccccccc
c Static Test Data for test s91003.001      c
c 2.00" x 1/4" strap    stance: 62.25"      c
ccccccccccccccccccccccccccccccccccccccccccc
           if(istrap.eq.1)then
              A0=  67.456792757
              A1=  28.437948412
              A2= 128.916354781
              A3= -10.778352233
              A4=   .423465819
              A5=  -.008005895
              A6=   .000058520
              sload=A0+A1*X+A2*X**2+A3*X**3+A4*X**4+A5*
     +         X**5+A6*X**6
ccccccccccccccccccccccccccccccccccccccccccc
```

```
c Static Test Data for test s91003.004      c
c 1.50" x 1.4" strap    stance: 62.25"      c
ccccccccccccccccccccccccccccccccccccccccccccc
          elseif(istrap.eq.2)then
               A0=   3.479778371
               A1= 165.721385040
               A2=  56.438120678
               A3=  -3.916548626
               A4=    .110840410
               A5=   -.001126658
               sload=A0+A1*X+A2*X**2+A3*X**3+A4*X**4+A5*X**5
ccccccccccccccccccccccccccccccccccccccccccccc
c Static Test Data for test s91003.006      c
c 1.25" x 1/4" strap    stance: 62.25"      c
ccccccccccccccccccccccccccccccccccccccccccccc
          elseif(istrap.eq.3)then
               A0=  74.941277074
               A1= 100.176010670
               A2=  61.962477984
               A3=  -4.938927317
               A4=    .179080909
               A5=   -.003003025
               A6=    .000017942
               sload=A0+A1*X+A2*X**2+A3*X**3+A4*X**4+A5*
     +          X**5+A6*X**6
ccccccccccccccccccccccccccccccccccccccccccccc
c Static Test Data for test s91003.00-      c
c 0.50" x 1/4" strap    stance: 62.25"      c
c NOTE: this curve is obtained by dividing  c
c   the 2.00 x 1/4 curve by 4               c
ccccccccccccccccccccccccccccccccccccccccccccc
          elseif(istrap.eq.7)then
               A0=  67.456792757
               A1=  28.437948412
               A2= 128.916354781
               A3= -10.778352233
               A4=    .423465819
               A5=   -.008005895
               A6=    .000058520
               sload=(A0+A1*X+A2*X**2+A3*X**3+A4*X**4+A5*
     +          X**5+A6*X**6)/4.0d0
ccccccccccccccccccccccccccccccccccccccccccccc
c Static Test Data for test s91003.008      c
c 2.00" x 3/16" strap   stance: 62.25"      c
ccccccccccccccccccccccccccccccccccccccccccccc
```

```
        elseif(istrap.eq.4)then
           A0=  100.885893198
           A1=  71.653095451
           A2=  55.315917665
           A3=  -4.651333630
           A4=   .179466952
           A5=  -.003231756
           A6=   .000021578
           sload=A0+A1*X+A2*X**2+A3*X**3+A4*X**4+A5*
     +        X**5+A6*X**6
ccccccccccccccccccccccccccccccccccccccccccccc
c Static Test Data for test s91003.010      c
c 1.50" x 3/16" strap   stance: 62.25"      c
ccccccccccccccccccccccccccccccccccccccccccccc
        elseif(istrap.eq.5)then
           A0=  98.234921359
           A1=  101.816583617
           A2=  21.843327063
           A3=  -1.940353269
           A4=   .084069291
           A5=  -.001745443
           A6=   .000013617
           sload=A0+A1*X+A2*X**2+A3*X**3+A4*X**4+A5*
     +        X**5+A6*X**6
ccccccccccccccccccccccccccccccccccccccccccccc
c Static Test Data for test s91003.012      c
c 1.25" x 3/16" strap   stance: 62.25"      c
ccccccccccccccccccccccccccccccccccccccccccccc
        elseif(istrap.eq.6)then
           A0=  111.692332306
           A1=  87.511583012
           A2=  24.255275066
           A3=  -1.744565826
           A4=   .051419306
           A5=  -.000547059
           sload=A0+A1*X+A2*X**2+A3*X**3+A4*X**4+A5*X**5
ccccccccccccccccccccccccccccccccccccccccccccc
c Static Test Data for test s91003.00-      c
c 0.50" x 3/16" strap   stance: 62.25"      c
c NOTE: this curve is obtained by dividing  c
c   the 2.00 x 3/16 curve by 4,             c
ccccccccccccccccccccccccccccccccccccccccccccc
        elseif(istrap.eq.8)then
           A0=  100.885893198
           A1=  71.653095451
```

```
                A2=  55.315917665
                A3= -4.651333630
                A4=   .179466952
                A5=  -.003231756
                A6=   .000021578
                sload=(A0+A1*X+A2*X**2+A3*X**3+A4*X**4+A5*
     +           X**5+A6*X**6)/4.0d0
            endif
      endif
      return
      end
```

```
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c                              Program Length
c                            JCR and KWP ©1992
c                       Theory presented in section 4.4
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c This code will calculate the length of a strap for a given stroke. The length is from three
c inches south of the south edge of the plate at the base of the clamp cage to the center of
c the idle roller. Strap lengths calculated by this code are from geometry only. The roller
c cage position is set to position 2.
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c     a_length     = the strap length between rollers not in contact with any roller
c     abmidx       = x coordinate of one of the points for a b_length term
c     abmidy       = y coordinate of one of the points for a b_length term
c     aterm        = the a term of the quadratic equation
c     b_length     = the strap length between the left probe roller and the clamp cage
c     bterm        = the b term of the quadratic equation
c     cdmidx       = x coordinate of one of the points for a b_length term
c     cdmidy       = y coordinate of one of the points for a b_length term
c     cterm        = the c term of the quadratic equation
c     ewspace      = the east-west distance between rollers 2 and 3 (fig. 4.4.1)
c     halfstance   = half of the stance distance
c     length_1     = subroutine to determine the strap length through the roller cage
c     length_2     = subroutine to determine the strap length of the rest of the strap
c     nsspace      = the north-south distance between rollers 2,3 and 4 (fig. 4.4.1)
c     radius       = the radius of the rollers
c     rmiddle      = the distance from the center of a roller to the center of the strap
c     sangle       = the sine of the contact angle
c     slength1     = strap length from length_1
c     slength2     = strap length from roller cage to probe center
c     slength3     = strap length from probe center through clamp cage
c     stance       = the stance distance in inches
c     stroke       = the displacement of the sled past the impact position
c     temp1        = a temporary variable
c     thick        = strap thickness
c     total_length = the total length of the strap
c     xmid12       = x coordinate of one of the points for an a_length term
c     xmid34       = x coordinate of one of the points for an a_length term
c     xmidab       = x coordinate of one of the points for an a_length term
c     xmidcd       = x coordinate of one of the points for an a_length term
c     ymid12       = y coordinate of one of the points for an a_length term
c     ymid34       = y coordinate of one of the points for an a_length term
c     ymidab       = y coordinate of one of the points for an a_length term
c     ymidcd       = y coordinate of one of the points for an a_length term
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
```

```
        include 'flib.fi'
        program Strap Length
        implicit real*8(a-h,o-z)
        implicit integer(i-n)
        real*8 nsspace
        integer*2 dummy
        character*1 resp1

        include 'flib.fd'
        dummy=aboutboxqq('Strap Length Calculator 1.0\r
     +  April 14, 1993'C)
cccccccccccccccccccccccccccccccccccccccc
c--> The user selects the stance being used
cccccccccccccccccccccccccccccccccccccccc
8       write(5,*)' '
        write(5,1)
        write(5,2)
1       format('  Select a stance or enter one...')
2       format('  1.) 62.25"',/,'  2.) 52.25"',/,'  3.) 32.25"',/,
     +         '  4.) 17.25"',/,'  5.) Other')
        read(5,*)iresp
        if(iresp.eq.1)then
                stance=62.25d0
                halfstance=31.125d0
        elseif(iresp.eq.2)then
                stance=52.25d0
                halfstance=26.125d0
        elseif(iresp.eq.3)then
                stance=32.25d0
                halfstance=16.125d0
        elseif(iresp.eq.4)then
                stance=17.25d0
                halfstance=8.625
        elseif(iresp.eq.5)then
                write(5,*)' Enter the stance in inches'
                read(5,*)stance
                halfstance=stance/2.0d0
        else
                goto 8
        endif
cccccccccccccccccccccccccccccccccccccccccccccc
c--> Select the strap thickness being used  c
cccccccccccccccccccccccccccccccccccccccccccccc
7       write(5,*)' '
        write(5,5)
```

```
5     format(' Select a strap thickness',/,' 1.) 1/4"',/,
   +        ' 2.) 3/16"',/,' 3.) Other ')
        read(5,*) jresp
        if(jresp.eq.1)then
                thick=0.25d0
        elseif(jresp.eq.2)then
                thick=0.1875d0
        elseif(jresp.eq.3)then
                write(5,*)' Enter the strap thickness'
                read(5,*)thick
        else
                goto 7
        endif
ccccccccccccccccccccccccccccccccccccccccccccc
c--> Read the stroke at the point in question  c
ccccccccccccccccccccccccccccccccccccccccccccc
3     write(5,*)' '
        write(5,4)
4     format('  Enter the stroke in inches')
        read(5,*)stroke
        write(5,*)' '
ccccccccccccccccccccccccccccccccccccccccccccccc
c--> East/West distance between rollers 2 and 3 c
ccccccccccccccccccccccccccccccccccccccccccccccc
        ewspace=0.625d0
cccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c--> North/South spacing between rollers 2,3 and 4       c
cccccccccccccccccccccccccccccccccccccccccccccccccccccccc
        nsspace=3.25d0
cccccccccccccccccccc
c--> Roller Radius c
cccccccccccccccccccc
        radius=1.25d0
cccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c--> Determine the strap length through the roller cage  c
cccccccccccccccccccccccccccccccccccccccccccccccccccccccc
        call length_1(nsspace,radius,thick,ewspace,slength1)
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c--> Determine the strap lengths from the roller cage to the center    c
c    of the probe and from the center of the probe through the clamp   c
c    cage. Includes the 13.5 inches of strap inside of the clamp cage. c
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
        call length_2(halfstance,radius,thick,stroke,slength2,slength3)
cccccccccccccccccccccccccccccccccccccccccccc
c--> Add the lengths of the individual parts  c
```

```
ccccccccccccccccccccccccccccccccccccccccccccc
        total_length=slength1+slength2+slength3
        write(5,6)total_length,stance,stroke,thick
c       write(1,6)total_length,stance,stroke,thick
6       format(' The strap length is    ',f8.4,/,
     +        ' The stance is         ',f8.4,/,
     +        ' The stroke is         ',f8.4,/,
     +        ' The strap thickness is ',f8.4)
        write(5,*)''
        write(5,*)' Do you wish to calculate another length for'
        write(5,*)' the same stance and strap thickness? Y/N'
        read(5,'(a1)')resp1
        if(resp1.eq.'y'.or.resp1.eq.'Y')goto 3
        stop
        end
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c--> Determine the strap length through the roller cage
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
        subroutine length_1(nsspace,radius,thick,ewspace,slength1)
        implicit real*8(a-h,o-z)
        implicit integer(i-n)
        real*8 nsspace
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c--> First solve the quadratic equation for the contact angle
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
        temp1=2.0d0*radius+thick
        aterm=ewspace*ewspace+nsspace*nsspace
        bterm=-2.0d0*nsspace*temp1
        cterm=temp1*temp1-ewspace*ewspace
        sangle=(-bterm-dsqrt(bterm*bterm-4.0d0*aterm*cterm))/
     +  (2.0d0*aterm)
        angle=asin(sangle)
        write(5,*)'angle= ',angle
        rmiddle=radius+thick/2.0d0
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c--> Determine the length of strap between rollers (not in contact)
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
        xmid34=nsspace-rmiddle*dsin(angle)
        ymid34=radius+thick-ewspace+rmiddle*dcos(angle)
        xmid12=rmiddle*dsin(angle)
        ymid12=radius+thick-rmiddle*dcos(angle)
        a_length=dsqrt((xmid34-xmid12)**2+(ymid34-ymid12)**2)
cccccccccccccccccccccccccccccccccccc
c--> Total Length in roller cage
cccccccccccccccccccccccccccccccccccc
```

```
      slength1=2.0d0*a_length+4.0d0*angle*rmiddle+1.8125d0
      return
      end
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c--> Determine the strap lengths from the roller cage to the center
c    of the probe and from the center of the probe through the clamp
c    cage. Includes the 13.5 inches of strap inside of the clamp cage.
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
      subroutine length_2(halfstance,radius,thick,stroke,slength2,
     +            slength3)
      implicit real*8(a-h,o-z)
      implicit integer(i-n)
cccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c--> First solve the quadratic equation for the contact angle  c
cccccccccccccccccccccccccccccccccccccccccccccccccccccccc
      temp1=2.0d0*radius+thick
      aterm=(halfstance-0.25d0)*(halfstance-0.25d0)+(stroke-temp1)*
     +   (stroke-temp1)
      bterm=-2.0d0*(halfstance-0.25d0)*temp1
      cterm=temp1*temp1-(stroke-temp1)*(stroke-temp1)
      sangle=(-bterm+dsqrt(bterm*bterm-4.0d0*aterm*cterm))/
     + (2.0d0*aterm)
      angle=asin(sangle)
      write(5,*)'angle= ',angle
      rmiddle=radius+thick/2.0d0
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c--> Determine the length of strap between rollers (not in contact)  c
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
      xmidcd=radius+0.25d0+rmiddle*dsin(angle)
      ymidcd=stroke-radius+rmiddle*dcos(angle)
      xmidab=halfstance+radius-rmiddle*dsin(angle)
      ymidab=radius+thick-rmiddle*dcos(angle)
      a_length=dsqrt((xmidcd-xmidab)**2+(ymidcd-ymidab)**2)
cccccccccccccccccccccccccccccccccccccccccccccccccc
c--> Total length from roller cage to center of probe  c
cccccccccccccccccccccccccccccccccccccccccccccccccc
      slength2=rmiddle+0.25d0+2.0d0*rmiddle*angle+a_length
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c--> Determine length of strap from center of probe through clamp cage c
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
      abmidx=thick/2.0d0*dsin(angle)
      abmidy=thick-thick/2.0d0*dcos(angle)
      cdmidx=halfstance-0.25d0-radius-(rmiddle)*dsin(angle)
      cdmidy=stroke-(radius+thick)+(rmiddle)*cos(angle)
      b_length=dsqrt((cdmidx-abmidx)**2+(cdmidy-abmidy)**2)
```

```
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c--> Total length from center of probe through clamp cage  c
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
      slength3=radius+0.25d0+middle*angle+b_length+thick/2.0d0
     +          +12.5d0
      return
      end
```

```
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c                          Program Triangle
c                            KWP ©1992
c                         September 3, 1992
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c This code reads in the output file, testdata.doc, from the pulse evaluation code and then
c prompt the user to indicate which of the FAR pulses is being evaluated. An ideal
c triangular pulse is then superimposed on the data. The ideal pulse is alligned with the
c peak of the actual pulse. An output file called "PLOT.DAT" is created which contains
c the channel class 60 data as well as the ideal triangle and the 0,10,90, and 100% lines if
c desired.
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c     B1,B2      = The Y intercepts of the equations for the ideal pulse
c     CC60       = An array of the Channel Class 60 data (G's)
c     CC180      = An array of the Channel Class 180 data (G's)
c     DELTAT     = The time difference between any two data points
c     DISP       = An array of the displacements of the test pulse (feet)
c     G10        = The value of 10% of the actual peak
c     G90        = The value of 90% of the actual peak
c     GMIN       = The peak G level seen in the test pulse
c     GMIN2      = A dummy variable used to locate the ideal peak G level
c     GPEAK      = The peak G level of the ideal pulse
c     GZERO      = The value zero g
c     IVEL       = A flag used when looking for the impact velocity
c     POINTS     = An array of the accelerations of the ideal pulse (G's)
c     SLOPE      = The slope of the ideal accel. vs time curve
c     TEND       = The ending time of the ideal pulse
c     TIME       = An array of the time values of the data points (sec.)
c     TMIN       = The time of the peak
c     TRISE      = The rise time of the ideal pulse
c     TSTART     = The starting time of the ideal pulse
c     TSTEP      = The time step between points in the ideal pulse
c     VEL        = An array of the velocity data (fps)
c     VO         = The impact velocity
c     XPEAKA     = The X displacement of the peak of the test pulse
c     XPEAKT     = The X displacement of the ideal pulse
c     XPOINT     = An array of the displacements of the ideal pulse (feet)
c     XTIME      = A time variable used to calculate ideal displacement
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
      implicit real(a-h,o-z),integer(i-n)
      character filename1*15,resp*1
      dimension time(4001),cc60(4001),cc180(4001)
      dimension vel(4001),disp(4001),points(4001),xpoint(4001)
      open(unit=1,file='plot.dat',status='unknown')
```

```
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c Input of the data file output from the pulse evaluation code. Data file must be time, class
c 60, and velocity.
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
      write(5,*)' Enter the name of the data file'
      read(5,1) filename1
1     format(a15)
      open(unit=2,file=filename1,status='old')
      gmin=35.0
      tmin=0.0
      ivel=1
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c--> The class 60 acceleration velocity and time are read in and the value and time of the
c minimum g is found
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
      do 2 i=1,4001
            read(2,*,end=5)time(i),cc60(i),vel(i)
            time(i)=time(i)
            if(cc60(i).le.gmin)then
                  tmin=time(i)
                  gmin=cc60(i)
            endif
cccccccccccccccccccccccccccccccccccccccccccc
c--> Search for the velocity prior to impact
cccccccccccccccccccccccccccccccccccccccccccc
            if(cc60(i).le.-0.5.and.ivel.eq.1)then
                  vo=vel(i-20)
                  ivel=-1
            endif
2     continue
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c--> Determine which pulse is being evaluated and the parameters of that pulse
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
5     call pulse(trise,gpeak,slope,xpeakt,vinit)
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c--> These values must be initialized prior to writing the ideal pulse to the file
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
      tstart=tmin-trise
      deltat=1.000e-04
      tend=tstart+2.0*trise
      tstep=trise/2.0
      b1=gpeak-slope*tmin
      b2=gpeak+slope*tmin
      gzero=0.0
      g10=0.1*gmin
```

```
      g90=0.9*gmin
      iend=i-1
      write(1,11) iend
      xtime=0.0
      gmin2=20.0
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c--> Loop through the time of the pulse and add the theoretical one to the test pulse
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
      do 3 i=1,iend
            if(time(i).lt.tstart.or.time(i).gt.tend)then
                  points(i)=0.0
            elseif(time(i).le.tmin)then
                  points(i)=slope*time(i)+b1
                  xtime=xtime+deltat
            else
                  points(i)=-slope*time(i)+b2
                  xtime=xtime+deltat
            endif
            write(1,10)time(i),cc60(i),points(i)
3     continue
10    format(3(2x,f12.5))
9     close(1)
      close(2)
      stop
      end
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c This subroutine prompts the user for the pulse being evaluated and then returns
c the rise time, peak G level, and slope of the onset line for the ideal pulse.
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
      subroutine pulse(trise,gpeak,slope,xpeak,vinit)
      implicit real(a-h,o-z),integer(i-n)
      write(5,10)
10    format(//////////)
9     write(5,*)' Please select which pulse is to be evaluated'
      write(5,11)
11    format(//)
      write(5,1)
1     format( ' 1.) Part 23   Test 1  19 G   50 ms')
      write(5,2)
2     format( ' 2.) Part 23   Test 1  15 G   60 ms')
      write(5,3)
3     format( ' 3.) Part 23   Test 2  28 G   50 ms')
      write(5,4)
4     format( ' 4.) Part 23   Test 2  21 G   60 ms')
      write(5,5)
```

```
5     format(' 5.) Part 25    Test 1  14 G    80 ms')
       write(5,6)
6     format(' 6.) Part 25    Test 2  16 G    90 ms')
       write(5,7)
7     format(' 7.) Part 27/29 Test 1  30 G    31 ms')
       write(5,8)
8     format(' 8.) Part 27/29 Test 2  18.4 G  71 ms')
       write(5,11)
       write(5,*)' Enter your selection'
       read(5,*)inp
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c--> The pulse parameters are defined based on the selection made
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
       if(inp.eq.1)then
             gpeak=-19.0
             trise=0.050
             xpeak=1.291671
             vinit=31.00
       elseif(inp.eq.2)then
             gpeak=-15.0
             trise=0.060
             xpeak=1.550007
             vinit=31.00
       elseif(inp.eq.3)then
             gpeak=-28.0
             trise=0.050
             xpeak=1.750006
             vinit=42.00
       elseif(inp.eq.4)then
             gpeak=-21.0
             trise=0.060
             xpeak=2.100009
             vinit=42.00
       elseif(inp.eq.5)then
             gpeak=-14.0
             trise=0.080
             xpeak=2.333347
             vinit=35.00
       elseif(inp.eq.6)then
             gpeak=-16.0
             trise=0.090
             xpeak=3.297818
             vinit=44.00
       elseif(inp.eq.7)then
             gpeak=-30.0
```

```
        trise=0.031
        xpeak=0.7734945
        vinit=30.00
      elseif(inp.eq.8)then
        gpeak=-18.4
        trise=0.071
        xpeak=2.485013
        vinit=42.00
      else
        goto 9
      endif
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c--> The slope of the onset line can be found from the peak g and the rise time
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
      slope=gpeak/trise
      return
      end
```

```
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c                          Program Speed
c                        JCR and KWP ©1992
c                   Theory presented in section 4.5
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c                This code will predict the speed of the sled
c                 at a given distance from its starting point.
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c The equations of motion of the sled are integrated using a fourth order
c Runge-Kutta method. There are two distinct time intervals for the
c integration. The first interval is from the time the sled starts until
c the firing valves are closed. The second interval is from the time the
c firing valves close until the sled reaches the impact position.
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c      a1()        = the acceleration of the sled with the firing valves open
c      a2()        = the acceleration of the sled with the firing valves closed
c      accel       = the acceleration of the sled at a point
c      area        = the cross sectional area of the piston
c      delay       = the time the firing valves are open
c      dint        = the displacement at the start of the second loop
c      disp        = displacement of the sled at a point
c      disp#       = displacement values inside time step intervals
c      disp_temp   = temporary displacement values for RK4 integration
c      f           = the friction force between the sled and the tracks
c      g           = gravity
c      gamma       = the specific heat ration for air (1.4)
c      loss        = the magnitude of the pressure loss force for a given pressure
c      patm        = atmospheric pressure
c      pload       = the sled payload weight
c      press       = the pressure acting on the piston at a given point in time
c      po          = the starting pressure of the system
c      t_by_2      = half of the time step
c      t_end       = the number of increments for the loops
c      time        = time since time zero
c      time_step   = time increment for one time through the do loop
c      smass       = the mass of the sled (slugs)
c      sweight     = the weight of the sled
c      vel         = the velocity of the sled at a point
c      vel#        = velocity values inside time step intervals
c      vel_temp    = temporary velocity values for RK4 integration
c      vol         = the initial volume of the air tanks
c      weight      = the total weight of the sled
c      xmax        = the distance to impact in feet
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
```

```
c NOTE: The "include" statements are only used if this code is to be
c      run through Microsoft Windows.
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
         include 'flib.fi'
         implicit double precision(a-h,o-z)
         double precision loss
         integer*2 dummy
         integer t_end
         character*1 resp
         common/const/area,dinit,f,gamma,g,loss,po,psipsf,smass,vol,patm
         common/extra/accel,disp,sweight,time,vel,xmax

         include 'flib.fd'
         dummy=aboutboxqq('Sled Speed Calculator 1.0\r
     +   April 14, 1993'C)
111      open(unit=2,file='speed.dat',status='unknown')
cccccccccccccccccccccccccccccccccccccccccc
c--> Enter the time the valves will be open           c
cccccccccccccccccccccccccccccccccccccccccc
         write(5,*)'Enter the delay time in seconds'
         read(5,*)delay
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c--> These values are set to zero here in case the code is restarted
c    before terminating.
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
         time=0.0d0
         disp=0.0d0
         vel=0.0d0
         accel=0.0d0
         press=0.0d0
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c--> These values are based on the number of segments desired for the two loops
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
         time_step=0.005d0
         t_end=delay/time_step
         t_by_2=time_step/2.0d0
         nflag=1
cccccccccccccccccccccccccccccccccccccccc
c--> Select the pressure of the system
cccccccccccccccccccccccccccccccccccccccc
         write(5,*)'Select a System Pressure or enter one'
         write(5,1)
1        format(' 1.) 50 psi',/,' 2.) 69 psi',/,' 3.) 75 psi'
     +   ,/,' 4.) 90 psi',/,' 5.) 100 psi',/,' 6.) Other')
         read(5,*)ivalue
```

```
cccccccccccccccccccccccc
c Pressure Loss Values     c
cccccccccccccccccccccccc
        if(ivalue.eq.1)then
c--> Loss for 50 psi  c
           po=50.0d0
           loss = 455.0d0
        elseif(ivalue.eq.2)then
c--> Loss for 69 psi  c
           po=69.0d0
           loss = 675.0d0
        elseif(ivalue.eq.3)then
c--> Loss for 75 psi  c
           po=75.0d0
           loss = 682.5d0
        elseif(ivalue.eq.4)then
c--> Loss for 90 psi  c
           po=90.0d0
           loss = 765.0d0
        elseif(ivalue.eq.5)then
c--> Loss for 100 psi  c
           po=100.0d0
           loss = 810.0d0
        else
           write(5,*)'Enter the pressure in psi and the loss value'
           read(5,*)po,loss
        endif
c--> Convert Pressure to psf
    po=po*144.0d0
        write(5,*)'Enter the weight of the sled payload'
        write(5,2)
2      format(' 1.) 1000 lbs',/,' 2.) 1250 lbs'
   +      ,/,' 3.) 1500 lbs',/,' 4.) 1750 lbs',/,' 5.) Other')
        read(5,*)jvalue
cccccccccccccccccccccccccc
c Friction Force Values      c
cccccccccccccccccccccccccc
        if(jvalue.eq.1)then
c--> 1000 lbs payload
           f=355.0d0
           pload=1000.0d0
        elseif(jvalue.eq.2)then
c--> 1250 lbs payload
           f=380.0d0
           pload=1250.0d0
```

```
        elseif(jvalue.eq.3)then
c--> 1500 lbs payload
            f=405.0d0
            pload=1500.0d0
        elseif(jvalue.eq.4)then
c--> 1750 lbs payload
            f=430.0d0
            pload=1750.0d0
        elseif(jvalue.eq.5)then
c--> Other payload
            write(5,*)'Enter the mass of the Payload in pounds'
            read(5,*)pload
            f=405.0d0+(355.0d0-405.0d0)*(pload-1500.0d0)/(-500.0d0)
        endif
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c--> Add payload weight to sled weight and convert to slugs
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
        weight=sweight+pload
        smass=weight/g
cccccccccccccccccccccccccccccccccccccccccccc
c--> First Loop
c   From time zero until the delay time
cccccccccccccccccccccccccccccccccccccccccccc
        do 10 i=1,t_end
                accel=a1(disp)
                press=po*(vol/(vol+area*disp))**gamma
                write(2,15) time,disp,vel,accel,(press-patm)/psipsf

                disp0=time_step*vel
                vel0=time_step*accel

                time=time+t_by_2
                disp_temp=disp+disp0/2.0d0
                vel_temp=vel+vel0/2.0d0
                disp1=time_step*vel_temp
                accel=a1(disp_temp)
                vel1=time_step*accel

                disp_temp=disp+disp1/2.0d0
                vel_temp=vel+vel1/2.0d0
                disp2=time_step*vel_temp
                accel=a1(disp_temp)
                vel2=time_step*accel

                time=time+t_by_2
```

```
                  disp_temp=disp+disp2
                  vel_temp=vel+vel2
                  disp3=time_step*vel_temp
                  accel=a1(disp_temp)
                  vel3=time_step*accel

                  disp=disp+(disp0+2.0d0*(disp1+disp2)+disp3)/6.0d0
                  vel=vel+(vel0+2.0d0*(vel1+vel2)+vel3)/6.0d0
10    continue
         write(2,15) time,disp,vel,accel,(press-patm)/psipsf
cccccccccccccccccccccccccccccccccccccccc
c--> Initialize values for second loop
cccccccccccccccccccccccccccccccccccccccc
         po=press
         dinit=disp
         t_end=4/time_step-t_end
         if(vel.gt.100.0d0)stop
         nflag=1
cccccccccccccccccccccccccccccccccccccccc
c--> Second Loop
c   From the delay time until impact
cccccccccccccccccccccccccccccccccccccccc
         do 20 i=1,t_end
                  accel=a2(disp)
                  disp0=time_step*vel
                  vel0=time_step*accel

                  time=time+t_by_2
                  disp_temp=disp+disp0/2.0d0
                  vel_temp=vel+vel0/2.0d0
                  disp1=time_step*vel_temp
                  accel=a2(disp_temp)
                  vel1=time_step*accel

                  disp_temp=disp+disp1/2.0d0
                  vel_temp=vel+vel1/2.0d0
                  disp2=time_step*vel_temp
                  accel=a2(disp_temp)
                  vel2=time_step*accel

                  time=time+t_by_2
                  disp_temp=disp+disp2
                  vel_temp=vel+vel2
                  disp3=time_step*vel_temp
                  accel=a2(disp_temp)
```

```
            vel3=time_step*accel

            disp=disp+(disp0+2.0d0*(disp1+disp2)+disp3)/6.0d0
            vel=vel+(vel0+2.0d0*(vel1+vel2)+vel3)/6.0d0

            press=po*(dinit/disp)**gamma
            write(2,15) time,disp,vel,accel,(press-patm)/psipsf
            if(disp.gt.xmax.and.nflag.eq.1)then
                    write(5,*)' '
                    write(5,16) time,disp,vel,accel,press/psipsf
                    nflag=2
            endif
20    continue
15    format(5(2x,f10.6))
16    format(' Time         =',f10.6,/,' Displacement =',f10.6,/,
   c     ' Velocity     =',f10.6,/,' Acceleration =',f10.6,/,
   c     ' Pressure     =',f10.6)
25    close(2)
      write(5,*)' Do you want to check another delay time? Y/N'
      read(5,'(a1)')resp
      if(resp.eq.'y'.or.resp.eq.'Y')goto 111
      stop
      end
cccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c Acceleration equation for sled with the tank valves open
cccccccccccccccccccccccccccccccccccccccccccccccccccccccc
      function a1(disp)
      implicit double precision(a-h,o-z)
      implicit integer(i-n)
      double precision loss
      common/const/area,dinit,f,gamma,g,loss,po,psipsf,smass,vol,patm
      a1=(po*area*(vol/(vol+area*disp))**gamma-
   +    (f+loss))/smass
      return
      end
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c Acceleration equation for sled with the tank valves closed
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
      function a2(disp)
      implicit double precision(a-h,o-z)
      implicit integer(i-n)
      double precision loss
      common/const/area,dinit,f,gamma,g,loss,po,psipsf,smass,vol,patm
      a2=((po*(dinit/disp)**gamma)*area-f-loss)/smass
      return
```

```
      end
cccccccccccccccccccccccccccccccccccccccccccc
c Data initializaion for program variables
cccccccccccccccccccccccccccccccccccccccccccc
      block data sleddata
      implicit double precision(a-h,o-z)
      implicit integer(i-n)
      double precision loss
      common/const/area,dinit,f,gamma,g,loss,po,psipsf,smass,vol,patm
      common/extra/accel,disp,sweight,time,vel,xmax
      data area/0.30679616d0/
c     data area_small/0.09851566d0/
      data g/32.174d0/
      data gamma/1.4d0/
      data psipsf/144.0d0/
      data vol/48.125d0/
c     data vol_small/16.041667d0/
      data disp/0.0d0/
      data xmax/61.0d0/
      data accel/0.0d0/
      data time/0.0d0/
      data vel/0.0d0/
      data smass/0.0d0/
      data sweight/1379.0d0/
      data dinit/0.0d0/
      data patm/2116.8D0/
      end
```